JULY, 1959 THREE SHILLINGS & SIXPENCE

NUCLEAR ENGINEERING

621

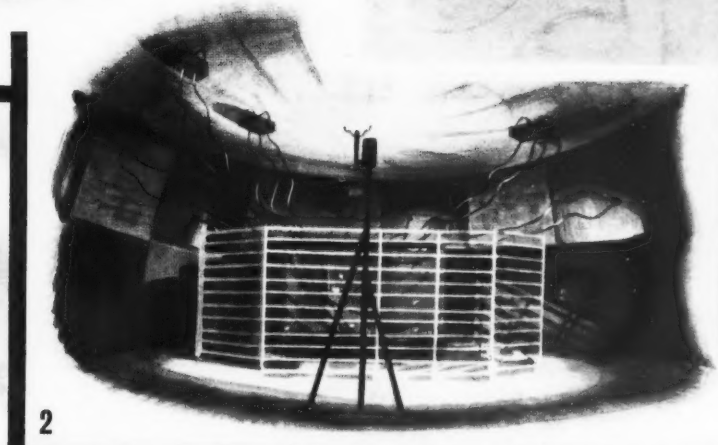
Berkeley reactor vessel pressure tested

THE JOHN CRERAR LIBRARY
JUL 8 - 1959

1 *X-raying a butt-welded joint.* A machine being moved into position for a shot on one of the circumferential welds.

2 *Stress-relieving.* The insulated bottom dome showing three of the eight inlet duct stubs. The temperature was recorded by 320 thermocouples, and the movement of the vessel was measured and recorded.

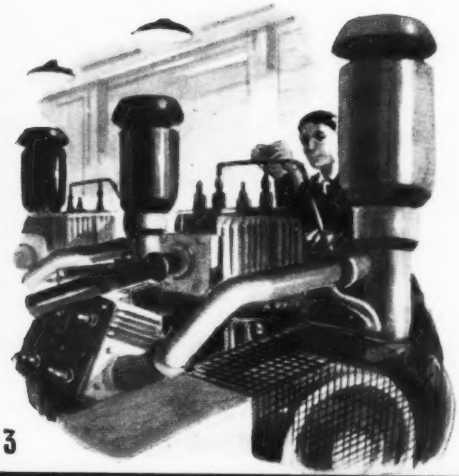
4



2

Some of the five compressors which raised the pressure inside the vessel to 210 p.s.i.

The panel of experts controlling the pressure test.

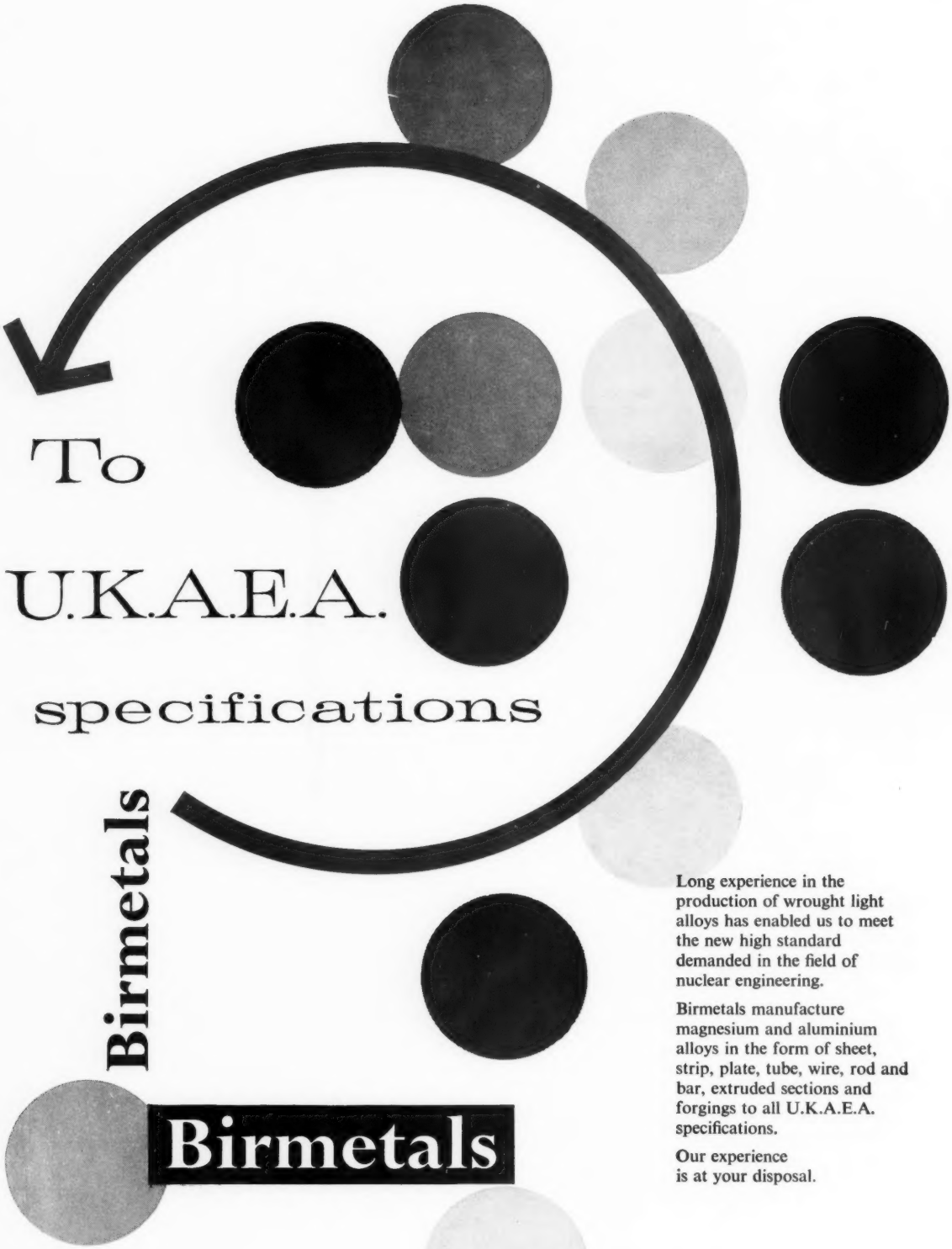


3

Having successfully passed its pressure test, No. 1 reactor at Berkeley has been accepted by Lloyds on behalf of the Central Electricity Generating Board.
Before pressure testing every welded joint had been 100% magnetically crack-detected. All butt-welded joints have been X-rayed to Lloyd's Class 1 requirements and the vessel was stress-relieved by being heated uniformly up to about 600°C. This heating and cooling operation took eleven days. Five compressors were installed to pressurize the vessel and the pressure was recorded in a temporary control room.

AEI
JOHN THOMPSON

Designers and builders of power and research reactors and nuclear power stations



Long experience in the production of wrought light alloys has enabled us to meet the new high standard demanded in the field of nuclear engineering.

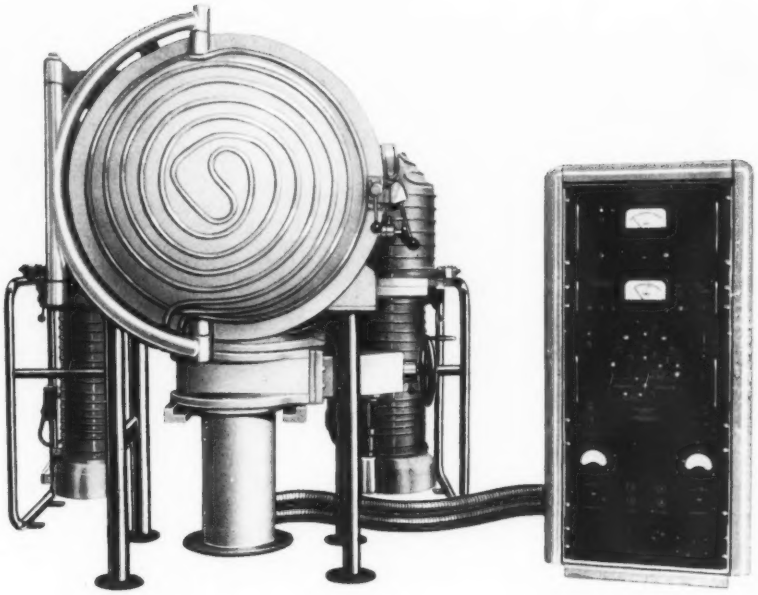
Birmetals manufacture magnesium and aluminium alloys in the form of sheet, strip, plate, tube, wire, rod and bar, extruded sections and forgings to all U.K.A.E.A. specifications.

Our experience is at your disposal.

BIRMETALS LIMITED · WOODGATE WORKS · BIRMINGHAM 32

BM 237

high vacuum furnace



TYPE FH30S

The VIA-VAC FH30S is specially designed for sintering of parts or for melting metals and vacuum casting by the bottom pouring method. The mould chamber is detachable, and, by fitting a top charging unit, the furnace can be operated continuously. Loading capacity, 25-50 lbs. of metal melt—ideal for small production and experimental work.

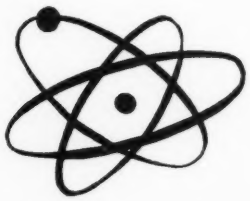
The standard range of VIA-VAC High Vacuum Furnaces embraces capacities from 5 lbs. to 3,000 lbs. melting and casting in the vacuum.

Metal degassing plant up to a capacity of 15 tons can also be supplied.

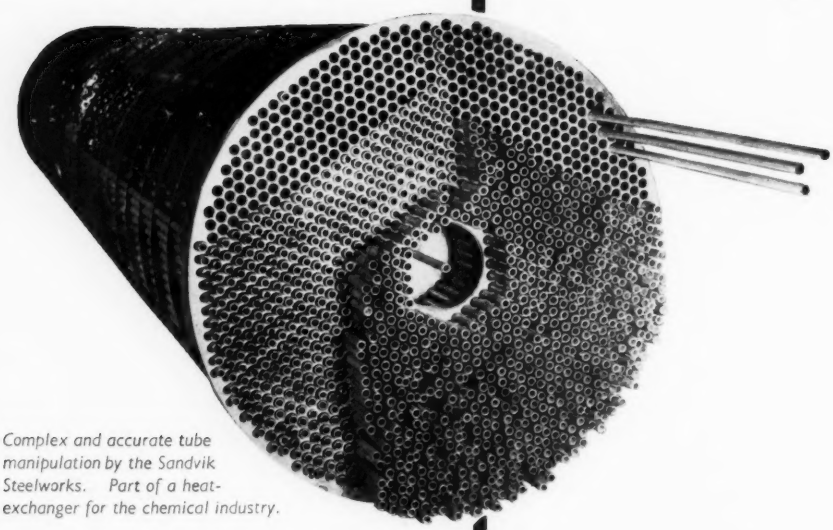
HIGH VACUUM CONSULTING
VIA-VAC
SERVICE TO INDUSTRY

VACUUM INDUSTRIAL APPLICATIONS LTD., **(Dept. N.E.) WISHAW, LANARKSHIRE, SCOTLAND**

Telegrams: "VIA-VAC, WISHAW" *Telephone: WISHAW 142*

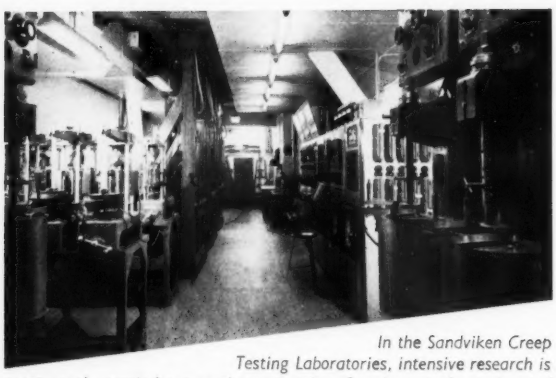


SANDVIK STEEL and nuclear energy



Complex and accurate tube manipulation by the Sandvik Steelworks. Part of a heat-exchanger for the chemical industry.

Special, high-purity steels are essential for the ancillary equipment of atomic reactors, such as heat-exchangers and coolers. The material must contain a minimum of those elements which can acquire persistent high radio-activity. Sandvik steel has the necessary purity and homogeneity and is backed by generations of steelmaking experience. Intensive research on the properties of steels at high temperatures has been going on for a very long time in the Sandviken laboratories. These facts help to explain why Sandviken is, to-day, exceptionally well prepared to meet the ever more stringent requirements of the Atomic Age.



In the Sandviken Creep Testing Laboratories, intensive research is continuously carried out on the properties of various steels at elevated temperatures

SANDVIK

THE SANDVIK STEEL WORKS CO. LTD.
SANDVIKEN · SWEDEN

IN GREAT BRITAIN:
SANDVIK SWEDISH STEELS LTD. · BIRMINGHAM

Darlington 85% magnesia keeps that heat where it is useful

Is the precious heat used in your plant leaking away through badly insulated pipes and furnaces —heat that now costs you more than ever before? Keep the air temperature down and the working temperature up by applying Darlington 85% Magnesia insulation; keep that heat just where it should be—working for you, not against you. Many British power stations, including the new atomic power station at Calder Hall, owe their high thermal efficiency to Darlington Insulation materials and engineering. If you have insulation problems contact our technical department first, they will give you as much help and advice as you need.

The Chemical and Insulating Co. Ltd

DARLINGTON, CO. DURHAM

TELEPHONE DARLINGTON 3547

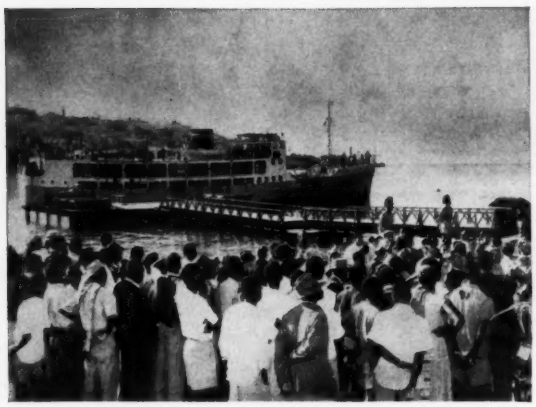
A member of the Darlington Group of Companies

MH3*

STOREY UNIFLOTES

VERSATILE FLOATING CONSTRUCTION UNITS

offer great scope for the construction of floating platforms of virtually any size or plan and for many different purposes.



Typical uses are for building landing stages, floating stages for harbour and bridge works, lifting camels, floating cranes and bridges, ferries and storage vessels, etc.

FOR FLOTATION, USE STOREY UNIFLOTES

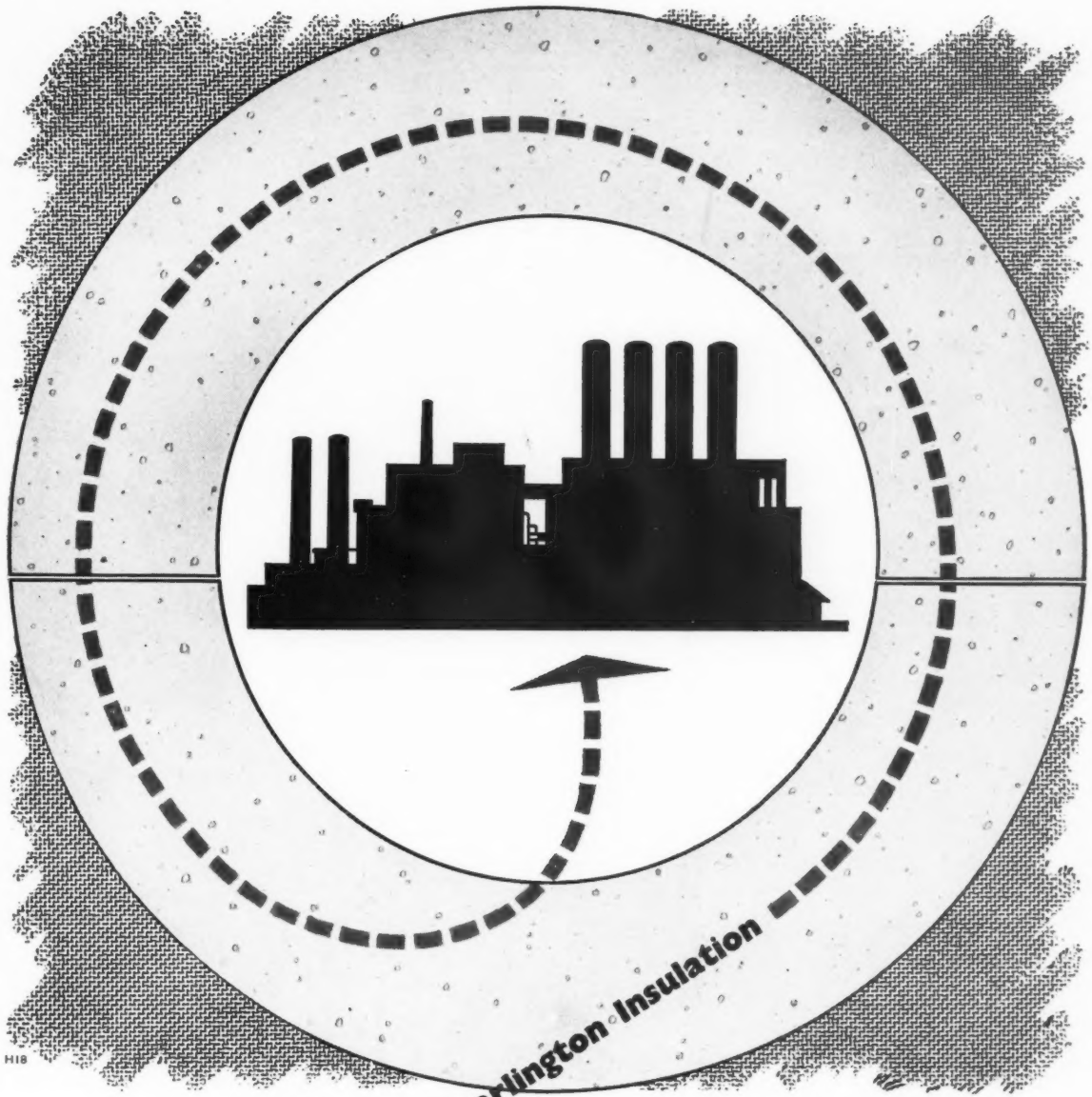
THOS. STOREY (Engineers) LTD.

WORLD LICENSEES FOR THE MANUFACTURE AND SALE OF BAILEY BRIDGING
PATENTEES AND MANUFACTURERS OF STOREY UNIFLOTES

STOCKPORT & LONDON ENGLAND

ENQUIRIES TO LONDON SALES OFFICE · 6 VICTORIA STREET · WESTMINSTER SW1

TELEPHONE: ABBEY 7391-2 TELEGRAM: MICROFAB SOWEST LONDON CABLES: MICROFAB LONDON



High Thermal efficiency means Darlington Insulation

Year after year the Central Electricity Generating Board's list of power stations with the highest operating efficiencies includes a majority of stations where the efficiency is guarded by Darlington Insulation. In the 1957 list, for example, the top four stations are Darlington insulated.
Coincidence ? Not a bit of it ! Just skill and years of experience, plus careful specifications and the right materials.
It's The Darlington Insulation Company's job to help maintain high thermal efficiencies, and they do it very well.

THE DARLINGTON INSULATION CO. LTD

38 Great North Road, Newcastle upon Tyne, 2
and branch offices at London, Birmingham, Bolton, Bristol, Cardiff, Glasgow, Leicester and Sheffield.

A Member of The Darlington Group of Companies

accent on

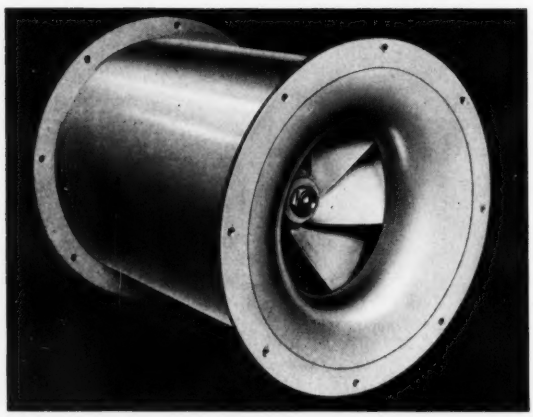
Research and Development

Evidence of the out-of-the-ordinary service that Keith Blackman render to industry and commerce in their need for fan engineering equipment is the accent placed on Research and Development. This exclusive service includes the use of laboratories specifically equipped for research into

axial and propeller fan design
centrifugal fan design
dust and air filtration
acoustics
metallurgy

now

The Ax-Cent Fan



A tangible result of the Keith Blackman service is the new AX-CENT COMPOUND FLOW FAN — Provisional Patent No. 3148/58. Externally similar to the conventional axial fan, the AX-CENT fan offers:

twice the pressure development
lower sound level & running speed
higher efficiency
centrifugal fan characteristics

Keith Blackman Ltd

MILL MEAD ROAD, LONDON N.17 TOTTENHAM 4522

Sales & Service Offices:

Birmingham, Bristol, Glasgow, Leeds, Leicester, London WC1, Manchester, Newcastle

940

MULTIRAIL
for extra rigidity
Proved under test to be as rigid as the solid forged type, the MULTIRAIL standard takes up to four rails. Where fewer rails are needed, vacant ferrules can carry power lines, and gas pipes, etc.
"SAFETREAD" FLOORING IS
tailor-made to each job!
Tailor-made and not just cut to fit, 'Safetread' flooring is no dearer to specify than ordinary steel flooring, but provides maximum strength with minimum of materials; non-skid surface; 82% light and air penetration; a neat fitting, clean appearance.
SAFETREAD
WELDED FLOORING
Write for detailed literature to
Allan Kennedy & CO. LTD.
MARITIME STREET · STOCKTON-ON-TEES
Telephone: Stockton 65464. Telegrams: Grating, Stockton-on-Tees.
Also at 207 Victoria Street, London, S.W.1

NUCLEAR ENERGY ENGINEER

Vol. 13 No. 134

JULY, 1959

CONTENTS

PAGE

ZED—New Research Reactor at Chalk River 337

Magnet for a Synchrotron 338

Marine Propulsion—The Admiralty Considers 340

Reactor Earthquake Tests 349

Lubricants in Nuclear Power Stations, by H. C. O'Connor, BSc, PhD 352

Research on Atomic Length Standards .. 354

Effect of Irradiation on Fuel Materials, Part II, by J. H. Kittel and S. H. Paine .. 357

Plutonium Fuel Fabrication Plant 361

Nuclear Energy Developments in Asia, by J. Burkett 365

Nuclearist Writes 368

Aldermaston's Tandem Van Der Graaf .. 369

People in the Nuclear News 371

Shape of Nucleus 372

Nuclear News 373

Plant and Materials 376

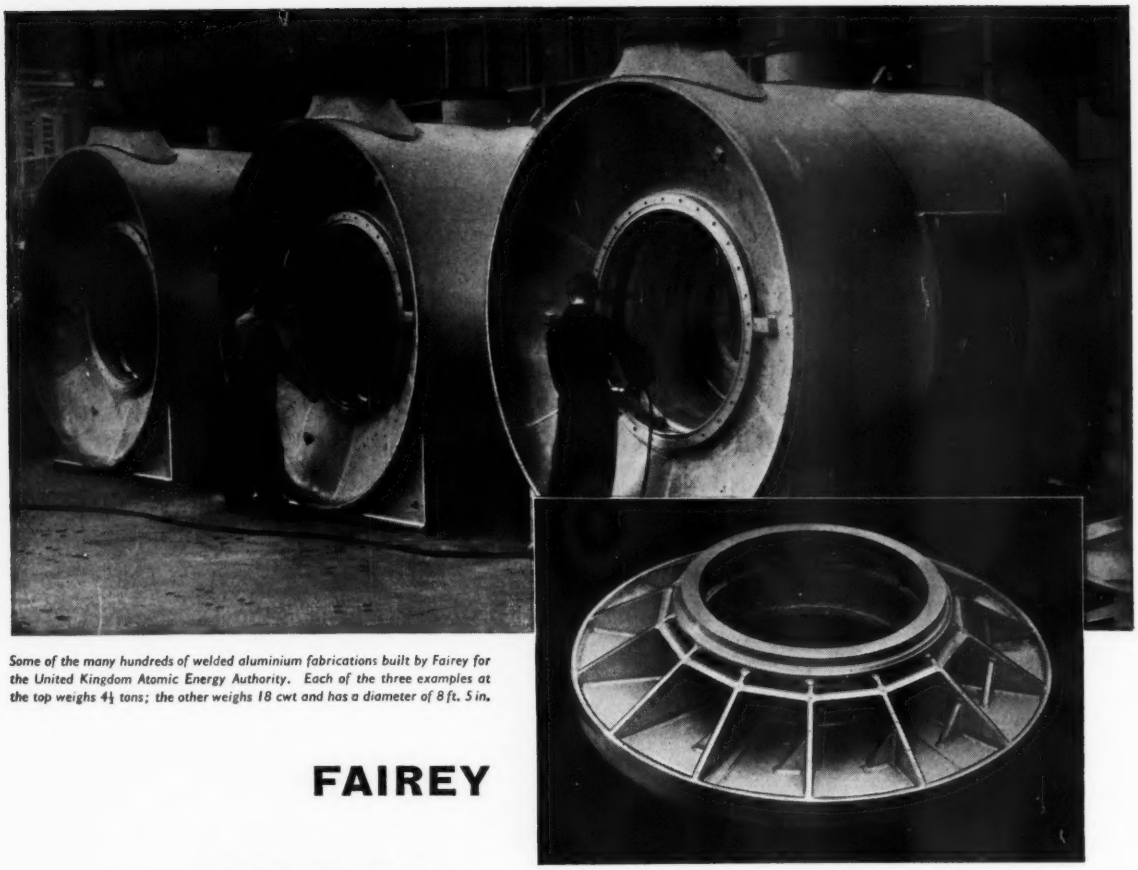
Contributors are invited to submit material for editorial consideration. Any matter which is required to be returned, should it prove unsuitable, should be accompanied by a stamped, addressed envelope. The Editor, to whom all contributions should be addressed, cannot accept responsibility for loss or damage to any material.

Subscriptions

Sterling Area :—12 monthly issues 42s. 0d. (including postage)

Americas :—$8.00

Other Countries :—As Sterling Area



Some of the many hundreds of welded aluminium fabrications built by Fairey for the United Kingdom Atomic Energy Authority. Each of the three examples at the top weighs 4½ tons; the other weighs 18 cwt and has a diameter of 8 ft. 5 in.

FAIREY PRESSURE VESSELS AND STRUCTURES IN STEEL AND ALUMINIUM

Fairey Engineering Ltd. offer a Fabrications facility equal to any in the world.

Pressure Vessels including refinery and chemical vessels, heat-exchangers, and large-diameter pipe, as well as many special types.

Structures such as bridge sections, roof trusses, crane jibs and oil derricks.

The Fairey Group of Companies provide a full Metallurgical Service, both in plant and at site, including X-Ray, vacuum and ultra-sonic testing; standards met include A.I.D., A.R.B. and U.K.A.E.A. and Lloyds Class I.

For vessels or structures . . . in steel or aluminium . . . talk to Fairey first

FAIREY ENGINEERING
LIMITED

STOCKPORT · CHESHIRE
A Subsidiary of The Fairey Company Limited

NUCLEAR ENERGY ENGINEER

The Leading International Journal on Nuclear Energy

Published Monthly *Price 3s. 6d.*

Editorial Director
J. B. Pinkerton, M.Cons.E., M.I.Mech.E.

Science Editor
D. S. Watt, B.Sc.

Editor
Ronald L. Sharp

Assistant Editor
Tony Rea

General Advertisement Manager
A. W. St. John Dillon

International Editors

Australia : Prof. Sir Leslie Martin, FRS, *University of Melbourne;* Prof. H. Messel, *University of Sydney;* Prof. H. C. Webster, DSc, PhD, *University of Queensland;* Prof. L. C. Woods, *New South Wales University of Technology.*

Belgium : Prof. Dr. J. L. Verhaeghe, *Ruksuniversiteit, Ghent.*

British West Indies : T. A. Jones, *Imperial College of Tropical Agriculture, Trinidad.*

Canada : Prof. A. R. Edis, *McGill University, Montreal;* Prof. A. C. Ghosh, *Carleton University, Ottawa;* Dr. G. W. Holbrook, *Royal Military College, Ontario.*

Ceylon : Prof. A. W. Mailvaganam, *University of Ceylon, Colombo.*

Denmark : Prof. Dr. Phil. V. Thorsen, *Danmarks Farmaceutiske Hojskole, Copenhagen.*

Federal Republic of Germany : Prof. Dr. med.h.c. Dr.-Ing.E.h. Dipl.-Ing. Leo Brandt, *Ministerium fur Wirtschaft und Verkehr, Dusseldorf.*

Holland : Ir. J. J. Arlman, *N.V. Philips-Roxane, Isotopes Commercial Dept., Amsterdam;* Ir. H. R. Kleyn, *Reactor Instituut, Delft;* Prof. Dr. A. C. Schuffelen, *Landbouwhogeschool, Wageningen.*

India : Prof. B. M. Anand, *Panjab University, Hoshiarpur;* Prof. D. R. Bhawalkar, *University of Saugar;* P. S. Gill, *Muslim University, Aligarh;* Dr. S. P. Pandya, *Gujarat University, Ahmedabad;* Dr. N. R. Tawde, *Karnatak University, Dharwar.*

Israel : Prof. Walter Fagan, *Israel Institute of Technology, Haifa.*

Japan : Dr. Masao Kato, *University of Tokyo;* Prof. Masaichi Mashima, *Keio University, Tokyo;* Prof. Keiji Nishioka, *Faculty of Engineering, Kanazawa University, Uenohon-Machi;* Dr. Noriyuki Sakikawa, *Tokyo Institute of Technology, Ookayama Meguro-ku, Tokyo.*

New Zealand : F. J. Llewellyn, *University of Canterbury, Christchurch;* Prof. D. Walker, *Victoria University of Wellington.*

Norway : L. Koren Lund, *Joint Establishment for Nuclear Energy Research, Lillestrom;* Prof. dr. B. Trumpy, *Universitetet I Bergen.*

Pakistan : Dr. Abdul Majid Mian, *Peshawar University.*

South Africa : Prof. J. A. Gledhill, *Rhodes University, Grahamstown;* Dr. H. R. Lemmer, *University of Pretoria;* Prof. F. R. N. Nabarro, *University of the Witwatersrand, Johannesburg;* Dr. J. P. F. Sellschop, *Witwatersrand University, Johannesburg.*

Sweden : Dr. Rune Alphonce, *Hogre tekniska laroverket, Orebro.*

United Arab Republic : Dr. S. I. El-Sisi, Dr. M. Z. Hathout, *Assiut University.*

United Kingdom : Prof. A. Charlesby, *Royal Military College of Science, Shrivenham;* M. G. Cooper, MA(Cantab), AMICE, *University of Cambridge;* Dr. T. G. Pickavance, *UKAEA, Harwell;* Prof. H. W. B. Skinner, FRS, *University of Liverpool.*

United States : Prof. G. Arfken, *Miami University, Oxford, Ohio;* Prof. S. Bashkin, *California Institute of Technology;* Prof. J. P. Bradish, *Marquette University, Milwaukee;* Prof. P. R. Camp, *Polytechnic Institute of Brooklyn, New York;* Dr. L. Cochran, *University of Kentucky;* Dr. B. E. Cohn, *University of Denver;* Prof. B. Crasemann, *University of Oregon;* Dr. J. W. Culvahouse, *University of Oklahoma;* Prof. H. J. Ermenc, *Dartmouth College, New Hampshire;* H. J. Gomberg, *University of Michigan;* G. A. Greathouse, *University of Florida, Gainsville;* T. M. Hahn, Jnr., *Virginia Polytechnic Institute, Blacksburg;* Dr. W. W. Havens, Jnr., *Columbia University, New York;* G. A. Hawkins, *Purdue University, Lafayette, Indiana;* Prof. V. P. Henri, *Northeastern University, Boston;* Prof. M. J. Jakobson, *Montana State University, Missoula;* Prof. J. A. Lockwood, *University of New Hampshire, Durham;* Dr. J. K. Major, *Western Reserve University, Cleveland;* Dr. S. F. Malaker, *Newark College of Engineering, New Jersey;* A. C. Menius, Jnr., *University of North Carolina, Raleigh;* Dr. G. Minard, *Bucknell University, Lewisburg, Pennsylvania;* V. E. Parker, *Louisiana State University, Baton Rouge;* Dr. F. B. Porzel, *Illinois Institute of Technology, Chicago;* J. A. Sauer, *Pennsylvania State University;* G. K. Schoepfle, *Kent State University, Ohio;* M. Schwartz, *University of Louisville;* Prof. W. E. Stephens, *University of Pennsylvania, Philadelphia;* Dr. C. D. Thomas, *West Virginia University, Morgantown;* Prof. L. Titone, *Manhattan College, New York;* Prof. B. Tolbert, *University of Colorado, Boulder;* R. E. Turley, *University of Utah, Salt Lake City;* Dr. J. Walton, *Oregon State College, Corvallis;* Prof. J. B. West, *Oklahoma State University, Stillwater.*

U.S.S.R. : Prof. Sheglyayev, *Moscow Technical Institute.*

Yugoslavia : Dr. M. V. Susic, *Institute of Nuclear Sciences, Belgrade.*

147 VICTORIA STREET, LONDON, S.W.1 Telephone: VICtoria 6423-4

A PRINCES PRESS PUBLICATION

THERMAL INSULATION

DATA with a DIFFERENCE

"Rule of Thumb" Tables have their obvious limitations. You often need to calculate heat losses, temperature gradients, economic thickness etc., where a departure from conventional standards is indicated. This Manual gives you the Data you need—the Basic Formulae with examples, tables and graphs and the theoretical considerations involved.

The Coupon entitles readers of *Nuclear Energy Engineer* to a complimentary copy. To apply, please attach the coupon to your letter heading.

CONTENTS

Theoretical Considerations
Conduction Through Solids
Surface Heat Losses
Heat Flow through Cylindrical Insulation

Thermal Conductivity "k"

Surface Factor "f"
Convection
Radiation

Surface Temperature
Temperature Gradients
Condensation

Composite Insulation

Insulation Efficiency

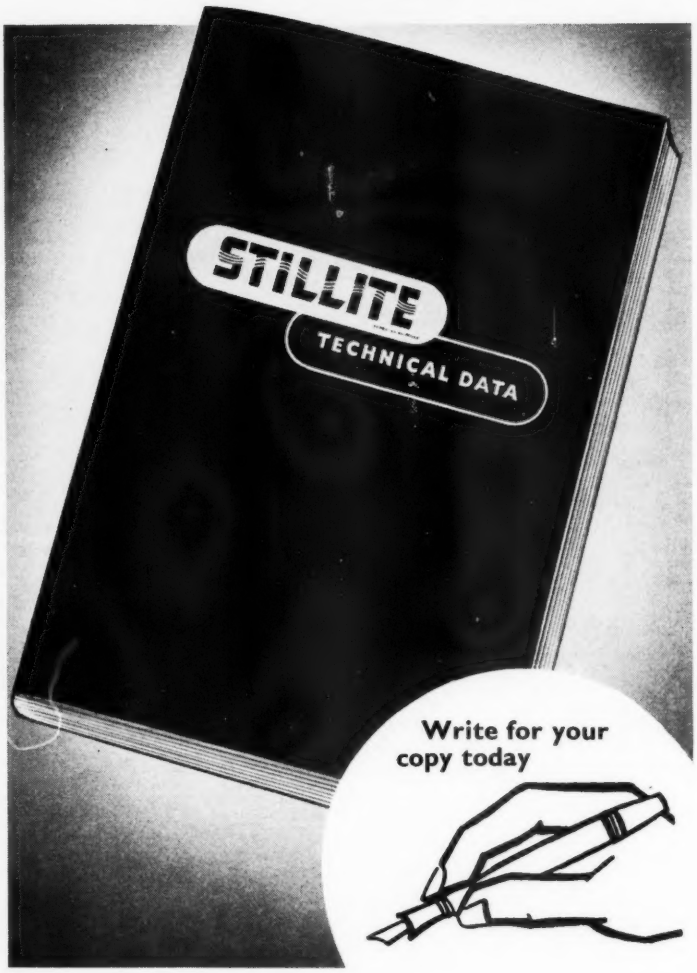
Economic Thicknesses

Thermal Conductivity Graph

Table of Surface area of insulation per Lineal Foot of Pipe

Table of Steam Temperatures/Pressures

Log Tables



STILLITE *Regd. Trade Mark*

INSULATION

STILLITE PRODUCTS LTD
15, Whitehall, London, S.W.1
Telephone: Whitehall 0922/6

and at 231, St. Vincent St.,
Glasgow, C.2
Telephone: Central 4292

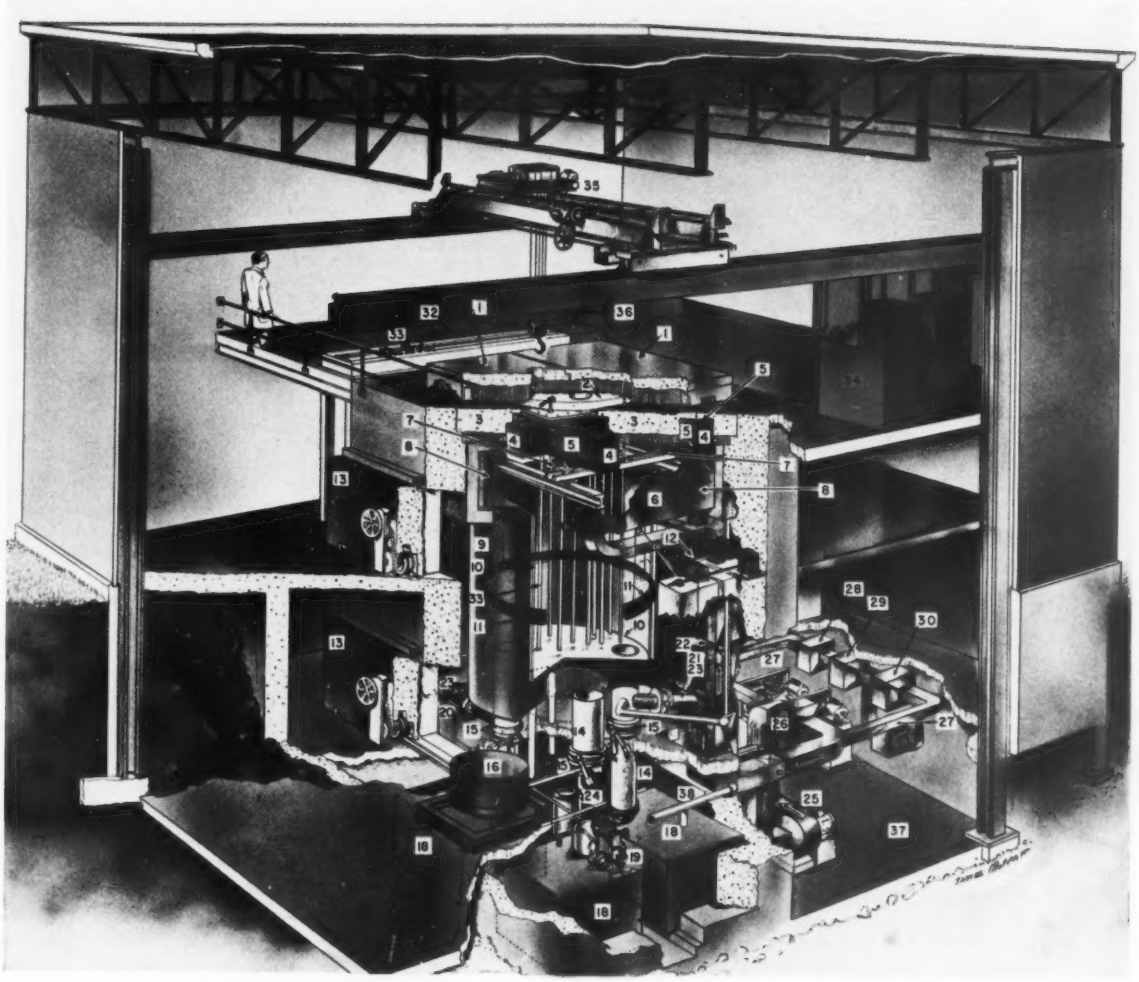
COUPON for complimentary copy of Stillite Technical Data Manual

NAME .....

ADDRESS .....

POSITION .....

NUCLEAR ENERGY ENGINEER



ZED–2

ANOTHER REACTOR FOR CHALK RIVER

1. Top rolling shield.
2. Reactor lid.
3. Top shielding (removable).
4. Neutron shielding.
5. Top shielding support beams.
6. Header room.
7. Fuel rod support lattice.
8. Lattice support.
9. Graphite reflector.
10. Calandria.
11. Control ring.
12. Control ring drive mechanism.
13. Concrete rolling doors.
14. D_2O fast dump pipes (three).
15. D_2O fast dump valves (V-1, V2, V3).
16. Removable bottom reflector.
17. Reflector dolly.
18. D_2O dump tanks (T_1, T_2, T_3).
19. D_2O pumps (P_{19}) P_{20}).
20. D_2O Calandria supply pipe.
21. Instrument still well.
22. Freezer—drier supply duct.
23. Freezer—drier return duct.
24. Hydraulic hoist for removable reflector.
25. Freezer drier fan (F6).
26. Freezer drier primary heater (C9).
27. Freezer drier cooling circuit duct.
28. Cooling coil " A " (water, 70°F.) (C9).
29. Cooling coil " B " (Freon, 40°F.) (C10).
30. Cooling coil " C " (Freon, —30°F.) (C11).
31. Refrigeration condensing.
32. Fuel rod storage rack.
33. Fuel rods.
34. Control console.
35. Twelve-ton bridge crane.
36. Location for rod pickling, washing and drying tanks.
37. Location for D_2O condensate recovery tanks.
38. Dump tank air vent line.

A LOW powered nuclear reactor specifically designed for testing the fuel arrangements in large reactors is to be installed at the Chalk River nuclear establishment by Atomic Energy of Canada Ltd. To be known as ZED-2, it will be used primarily to investigate the physics of fuel for large power stations such as the CANDU (Canadian Deuterium Uranium) Plant for which a preliminary design is now being produced at AECL's Nuclear Power Division in Toronto.

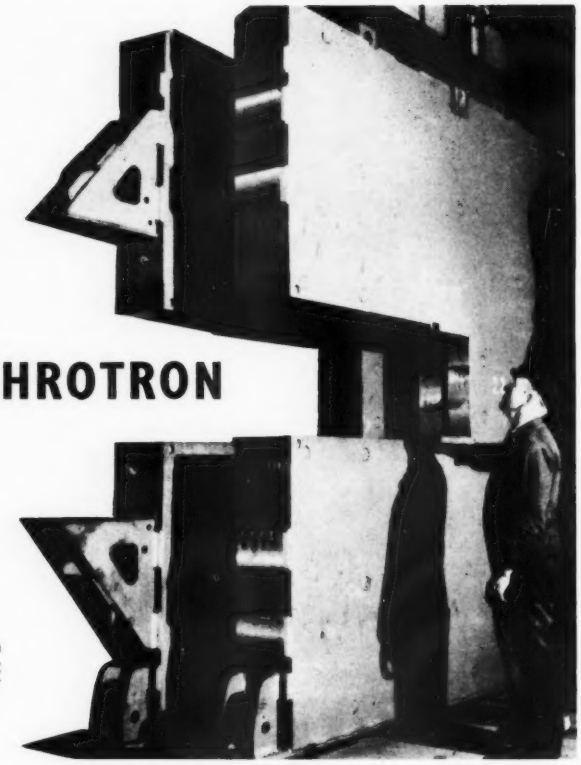
Construction of the reactor and its engineering are being undertaken by Foster Wheeler Ltd., of St. Catharines, Ontario. It will cost about $\frac{3}{4}$m.

ZED-2 which is expected to go into operation by early next year, will have a power or heat output of 100w. It will be moderated with heavy water (about 25 tons of it) and in the early experiments will use bundles of uranium oxide rods as fuel. A normal fuel loading will weigh about 10 tons.

The reactor is similar in general design to ZEEP, the 100w reactor which went into operation at Chalk River in 1945. It is, however, larger, to permit fuel experiments that cannot be performed in ZEEP. Another feature of the new reactor is the apparatus for changing fuel rod arrangements by remote control. This will speed up experiments.

The core of ZED-2 is an aluminium tank 10ft in diameter and 11 ft high containing heavy water. Fuel rods are suspended in the tank and the power of the reactor is controlled by changing the height of the heavy water.

The 7,000 ton magnet core for the 7 GeV proton synchrotron being constructed at Harwell is being fabricated in 336 separate sectors, at the rate of one a day. This article describes the care and precision that has to go into the production of each of these sectors.



MAGNET FOR A SYNCHROTRON

CONSTRUCTION of the 7GeV proton synchrotron for the National Institute for Research in Nuclear Sciences at Harwell is well under way. One of the major components for this machine is a 7,000 ton magnet core, the installation of which was recently started and which is not expected to be completed until May of next year.

Two of the 20-ton sectors of the magnet core of the 7 GeV proton synchrotron

Said to be the largest magnet ever to be built in the British Commonwealth and the heaviest in Europe outside the U.S.S.R., it is being built in 336 sectors, each sector weighing almost 20 tons and measuring 10 ft 5 in. high, 9 ft 3 in. wide and 12½ in. thick. Diameter of the completed magnet will be 160 ft.

The sectors are being manufactured by Joseph Sankey & Sons Ltd., of Wolverhampton, at the rate of one a day. Before production could start many difficulties and problems had to be overcome. A continuous production line had to be established, for instance and because of the tremendous handling problems involved special handling and tackling equipment had to be installed. Furthermore, by the nature of the project it was essential to ensure that the high precision requirements of the Institute could be met.

Forty Five Plates

Each magnet sector is made up of 45 silicon steel plates, each of which has to be flawless, level and completely insulated from its neighbour. Experts spent 12 months finding the correct annealing process so that the steel plates met the requirements for accuracy and magnetic properties. A new welding machine had to be developed to enable each plate for the sector to be formed from two smaller sections, no steel sheet large enough for the whole plate being made in Britain. Development of the machine was undertaken by Quasi-Arc, Ltd.

The temperature for each sector had to remain constant to within three-quarters of one degree of Centigrade during the final machining, as even the slightest variation in temperature would cause surface distortions. The slightest error is very serious as the throat of the C-shaped magnet has to be accurate to within 0.005 in. and both faces no more than 0.004 in. out of flat or out of parallel to each other.

Why The Accuracy

This accuracy is essential if the proton synchrotron is to do its job properly. The throat of the magnet will carry a vacuum tube through which a beam of protons will be accelerated and the slightest distortion in the magnet will seriously affect the rotation of the beam.

At all stages of production every care is taken not only in ensuring utmost accuracy but also in reducing the risk of possible difficulties cropping up at a later stage. For instance, the ¼ in. and ½ in. steel plates are marked for cast, ingot and position of ingot as they come in from the mill before being stored. They are then drawn from stores when required in such a manner as to randomize any variations within each cast.

Two at a Time

After being drawn from stores a pair of plates are selected and inspected, two edges of each plate sheared at right angles and the rough profile of the magnet throat cut out. The two plates are then welded together to form a complete lamination.

The laminations are annealed to flatten them, homogenize their structure and to optimize their electrical properties. The treatment consists of heating a stack of plates in a bell type furnace to a temperature of around 800°C. and then cooling them.

During the annealing process the plates are supported by means of pieces of cold reduced 0.013 in. strip of varying widths. These are inserted to compensate for the barrel shape of the plates, which are thicker in the centre than at the sides.

The annealing process takes about 16 days—eight to reach the annealing temperature of 800°C. and another eight for the plates to cool down.

Each sector is made up of plates taken from at least five casts. This is to help reduce the risk of an accumulation of repetitive distortions which might occur if all the plates were taken from one cast.

Next stage is the shearing of the plates on all four sides true and square to each other to a $^1/_{32}$ in. tolerance, followed by drilling of necessary assembly holes and then the complete removal of all scale and surface defects. It is of paramount importance that the surface finish of the plates should be of a very high standard and a great deal of experimental work in the method and application of defraying equipment was carried out before the present procedure was adopted.

Using an overhead crane fitted with large lifting magnets the plates are placed upon a table which is 30 in. above floor level. An electrically operated sanding machine equipped with cloth based silicon carbide abrasive strip is then passed across the surface of the plate in two directions.

Defraying Process

The plate is then transferred to a second table for the deburring of all the holes and edges with Consolidated Pneumatic portable sanders.

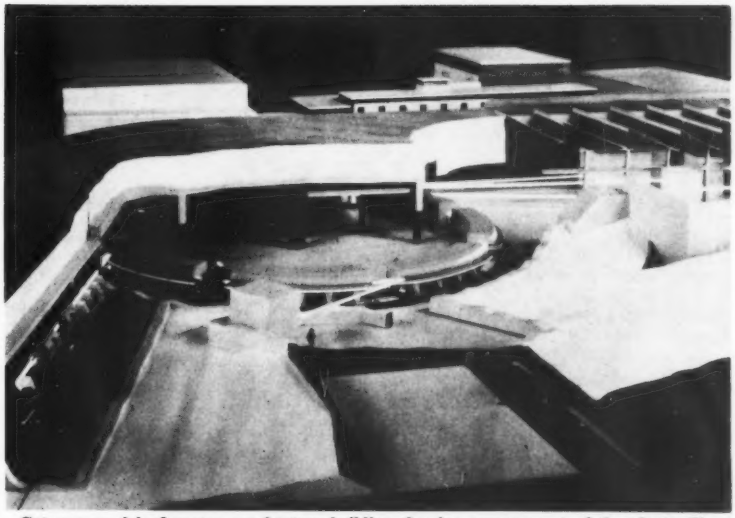
After a sector has been defrayed and passed by inspection the plates are placed in a steam coil heated soaking pit where they are subjected to a temperature of about 80°C. After removal from the pit the plates are weighed.

Each sector contains 42 or 43 $\frac{1}{4}$ in. laminations with or without one $\frac{1}{8}$ in. lamination. The weight can be controlled to $\pm$252 lb on a total weight of 41,944 lb by varying the number of laminations.

Insulating the Sections

After weighing, the laminations are sprayed on the top side with DRNS, an insulating coating specially developed by Sankey for application to electrical laminations. Extra inter-lamination insulation is provided around the throat area.

Fabrication of the sectors takes place in a bed shaped to suit the final shape of the side of the sector. The shape of the sectors is influenced by the amount of crown in the half plates.



Cutaway model of proton synchrotron building showing arrangement of the plant. The white line indicates the path taken by the proton beam

The $\frac{1}{4}$ in. plates are laid on top of each other with a $\frac{1}{2}$ in. plate as a base, each plate being covered with insulating paper and narrow crown compensation paper along the edges. The additional insulation around the throat area is also coated with resin. A $\frac{1}{2}$ in. plate goes on top of the stack.

As each plate is placed in position an electric resistance reading is taken with an Avo meter between each pair of adjacent plates. Fourteen insulated tie bolts are inserted and tightened to 20 ft.lb with a torque wrench. A separate shaped grid is positioned on top of the sector and 50 tons of weight distributed equally on the grid.

Thickness checks of the sector are taken. Thickness within the throat area must be within 12.710 in. and 12.860 in. and along the back and edges must not exceed 12.5 in.

Side plates are welded in position, the weights and grids removed, and the tie bolts tightened to 100 ft.lb torque.

The sector is then stood up on end and transferred to another part of the factory where it is sprayed with a grey paint, and then stood for seven days before machining.

Machining Operations

The sequence of machining operations carried out on the completely fabricated sector is as follows:—

Machine the active section of the throat to within .020 in. of finished size and to a tolerance of $\pm$0.005in.

Rough and finish machine the rear section of the throat to a final tolerance of $\pm$0.015 in.

Machine one half of one degree of taper on rear of sector for full height of 10 ft 5 in. to a tolerance of 5 min on angle and +0.0 in. −0.02 in. on thickness.

Rough and finish machine two $2\frac{1}{2}$ in. × $1\frac{1}{2}$ in. slots in throat to a tolerance of $\pm$0.030 in.

Finish machine the active faces of the throat to a tolerance of $\pm$0.005 in. and total tolerance of .004 in. on parallelism of the two faces relative to one another.

Machine four pads on the front of the sector to provide an accurate datum for fixing coil brackets.

After the sector has been completely machined the two coil bracket assemblies are jigged in position and sequence welded in place. The sector is then stood for at least 12hr to allow the heat of welding to dissipate.

After this it is given a final coat of paint and taken by crane to the final inspection stand where a complete dimensional check is made. A coat of strippable lacquer is given to the machined surfaces and the sector is completed ready for despatch to Harwell by road transport. A completely enclosed holding fixture is provided for this journey.

JAPANESE PROJECT

AMONG designs for a nuclear powered ship being considered by the Japan Atomic Energy Commission's sub-committee on nuclear marine propulsion is a plan submitted by the Uraga Dock Co. Their vessel would be powered by a light water moderated pressurized water reactor giving it a speed of 20 knots and a cruising range of 500,000 km.

MARINE PROPULSION

The Admiralty Considers . . . .

Eight designs for the reactor system to be used in Britain's first commercial nuclear powered ship have been submitted to the Admiralty by British industry and the UKAEA. They are now being examined from technical, economic and safety aspects. This will be a lengthy business and the Admiralty have made no promises as to when their final choice of one of the systems for practical development will be announced. Available details of the systems are published in the following pages. Some of the organizations submitting proposals have been generous with information, others far less so—the UKAEA have released nothing more than that their proposal makes use of an advanced gas cooled reactor system. (Some theoretical data on this system as applied to marine propulsion was given at Geneva. Reference to this data is made on page 348). At present the Admiralty plans to develop only one reactor system for marine propulsion; at a later date it is likely that a second system will be tried out.

BABCOCK & WILCOX

PWR System

THE project submitted by Babcock & Wilcox Ltd. is for plant incorporating a reactor of the pressurized-water type. It is basically similar to the plant now in an advanced state of construction by the Babcock & Wilcox Co., of America, for *N.S. Savannah*, but is designed for a power output 2½ times greater than that for *Savannah*, and to take up only 20 per cent. more space. Total weight of plant is about 3,000 tons and output of the reactor 180 MW.

In a pressurized-water reactor plant, ordinary water is used as the reactor-coolant and also as the moderator of the fission-process. Raised to a high pressure and temperature by absorption of heat from the reactor core, this water is circulated through heat exchangers which generate steam to drive conventional turbine propulsion machinery. The fuel is enriched uranium, the degree of enrichment ranging from 2 per cent. to 4 per cent., depending on whether stainless steel or zirconium is used for the cladding and structure of the reactor core.

Nine Tons of Fuel

A fuel charge of about 9 tons would be sufficient for 500 days seagoing service at full power before refuelling was necessary. This corresponds to 2 to 5 years service, depending upon the type of vessel and the nature of the voyages.

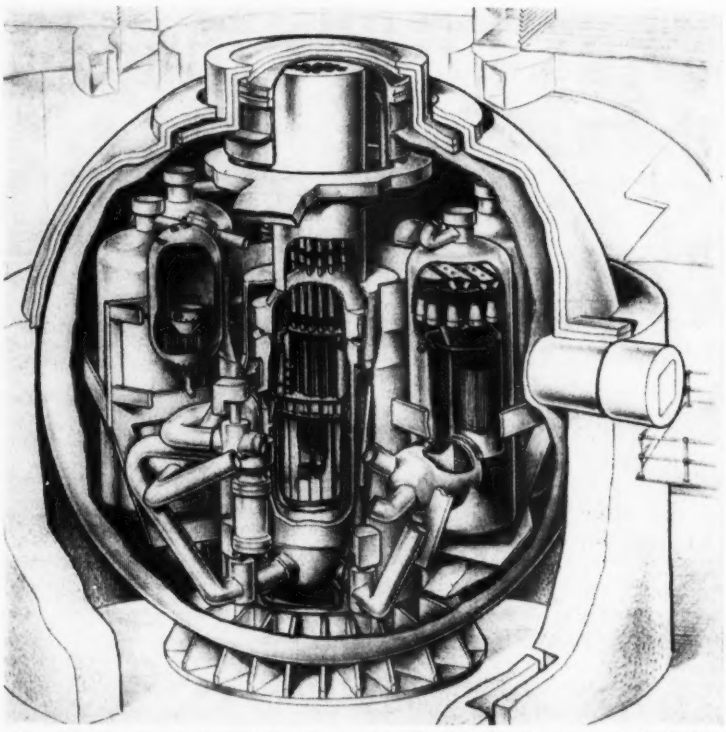
The weight of the complete plant, i.e., approximately 3,000 tons, is equivalent to one week's supply of fuel-oil for the conventional boilers of a propulsion plant developing the same horsepower in the same type of vessel.

The heat output of the reactor is designed to produce a shaft h.p. of 65,000.

The cost of the complete plant will depend largely on the requirements of any precautions, e.g., resistance to shock, and measures to meet special port regulations, etc., additional to the many safety measures already fully embodied in the design.

The cost of fuel will lie between 0.3d. and 0.6d./s.h.p./hr depending on the type of fuel element employed and the source from which it is obtained.

The pressurized water reactor system is basically simple, robust, safe and inherently



Arrangement of the pressurized water reactor plant of the *NS Savannah* inside its containment vessel

stable in operation. In the Babcock project great attention has been paid to requirements of safety from all aspects e.g.:—

1. It is so designed that there will be natural circulation in the event of a pump failure.

2. The large water-capacity of the boilers allows adequate time for emergency action by providing a "buffer" between the requirements of reactor and turbine.

3. Ample provision has been made against any general boiling of the coolant; which could result in instability and formation of deposits in the reactor circuit.

4. The reactor would be capable of operating continuously at full power with as much as 5 per cent. of the fuel elements in a failed condition; a most unlikely event.

5. The turbines and condensers are completely isolated from the reactor coolant circuit, so preventing any mutual contamination.

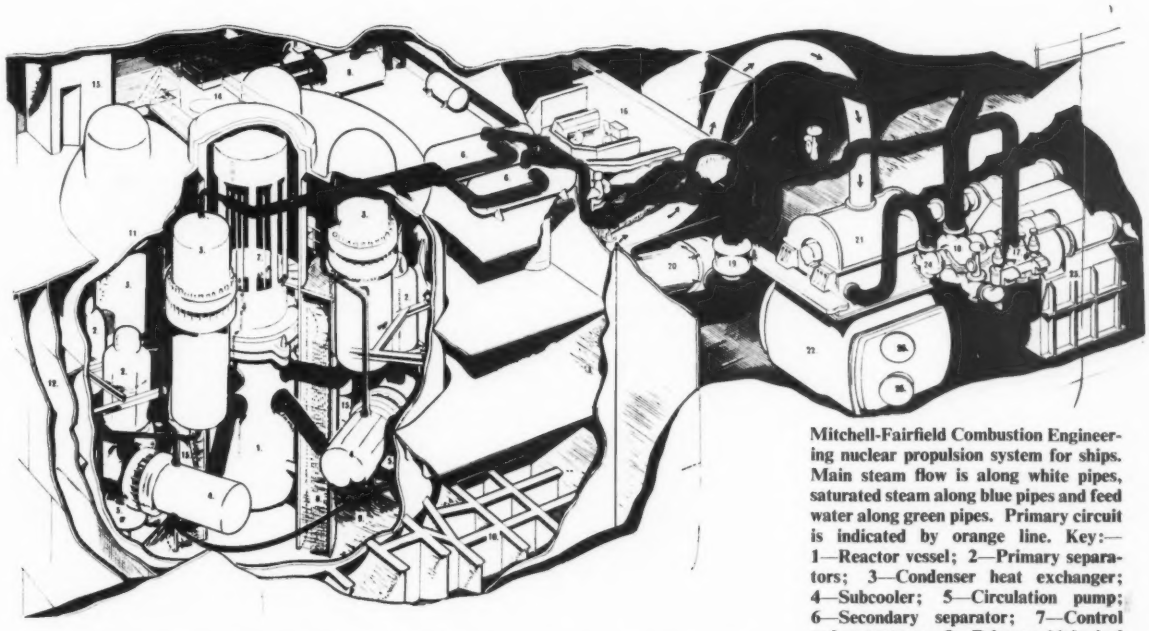
6. The appropriate water treatment can therefore be applied to each circuit and the resulting purity of the coolant water minimizes any induced radioactivity. Hence approach to plant within the containment vessel for maintenance etc., is possible within minutes of shut down.

7. The strength of the containment vessel is more than adequate to prevent the escape of any radioactive material in the event of mishap to any or all of the pressure parts in the reactor and boiler circuits housed within the vessel.

8. As no special fluids are used, several alternative methods can be employed to replenish the coolant and moderator in the event of an emergency.

MITCHELL GROUP

Closed Cycle BWR



Mitchell-Fairfield Combustion Engineering nuclear propulsion system for ships. Main steam flow is along white pipes, saturated steam along blue pipes and feed water along green pipes. Primary circuit is indicated by orange line. Key:— 1—Reactor vessel; 2—Primary separators; 3—Condenser heat exchanger; 4—Subcooler; 5—Circulation pump; 6—Secondary separator; 7—Control rod actuators; 8—Primary biological shielding; 9—Containment compartment water storage tanks; 10—Containment seating structure; 11—Containment compartment and secondary shielding; 12—Cofferdam; 13—Health physics room; 14—Containment access platform; 15—Primary isolating valve; 16—Control room; 17—Sequential nozzle control valves; 18—H.P. ahead turbine; 19—Steam separator; 20—Reheater; 21—L.P. turbine; 22—Main condenser; 23—Reduction gearing; 24—H.P. astern turbine; 25—Main circulating water connections

A CLOSED cycle boiling reactor design has been submitted by the Mitchell-Fairfield Combustion Engineering consortium. The plant which incorporates four heat exchanging loops, each loop comprising a primary separator, a condenser heat exchanger, a sub-cooler, a circulating pump and associated pipework and valves, is designed to produce steam for two sets of 25,000 s.h.p. engines and all power plant and ship auxiliaries.

The reactor is rated at 175 MW, but at full power the thermal output would be 156 MW. The core comprises 216 fuel assemblies each of which contains 56 fuel rod elements. A fuel element consists of a 0.366 in. inner diameter stainless steel tube, of wall thickness 0.015 in. and approximately 8 ft long, filled with cylindrical uranium dioxide pellets, bonded with helium gas and sealed at both ends by means of a welded cap. Two types of elements will be used within each assembly. Type 1 elements will contain 2.55 per cent. enriched UO_2 pellets; type 2 elements will contain half enriched UO_2 pellets and half natural UO_2 pellets. Type 2 elements will be placed at each corner of fuel assemblies to control hot spots caused by the high flux in the water channels outside the fuel boxes and to reduce axial neutron flux variation. The fuel elements are guaranteed for a burnup of 11,023 KWD/kg.

Control Rods

In order to obtain adequate control of the reactor, 21 control rods fabricated from three different combinations of neutron absorbing materials will be used as follows:

(i) *The centre rod.* The poison section of this control rod is liable to be in the core rather more than any other control rod and is therefore made entirely of hafnium.

(ii) *The four control rods surrounding the centre.* For these pure hafnium would be used for approximately 60 per cent. of the poison section and the remainder would be made of boron stainless steel; i.e., stainless steel containing 2 per cent. by weight of natural boron.

(iii) *The scram rods.* These are the remaining 16 outer rods, and as they are normally held full out of the core and only used for reactor scrams, the posion sections would be entirely made of boron stainless steel.

The reactor vessel is of the vertical type, cylindrical in shape and having an inside diameter of 9 ft and a length over the heads of approximately 23 ft 10 in. The vessel weighs approximately 90 tons including the internals but excluding the core and control rods. It is constructed of carbon steel 4 in. thick and clad with stainless steel 0.2 in. thick.

The primary biological shield comprises a 3 ft 6 in. wide annular borated water tank extending throughout the height of the

reactor vessel. In addition to this the shielding in a radial direction from the core throughout a distance several feet greater than its height consists of approximately 4½ in. stainless steel, 7 in. light water, 15 in. mild steel, 4 in. stainless steel thermal insulation, 19 in. air gap and 1 in. lead. The shielding in the radial athwartships direction is supplemented by a 2 ft 6 in. thickness of light water formed by the quench tanks.

The main secondary shield structure is the containment vessel on to which is applied lead of varying thickness from 3 in. to 6½ in. depending on the radiation levels within and permissible levels without. Local shielding round particularly active equipment supplements the main shield.

Containment

The containment compartment is designed to house the reactor proper together with the four primary circulating loops and associated equipment. In shape it approximates to an ellipsoidally headed, flat bottomed cylinder.

It performs the following four main purposes:

(i) Containment of radioactive fluids in the event of a maximum credible accident.

(ii) Containment of radioactive fluids in the course of normal operation.

(iii) Support for secondary shielding.

(iv) Additional protection for core in case of hull damage.

When the reactor is in operation, there will be no necessity for access to the containment compartment and so under all reactor operating conditions admission will be prohibited. After shutdown, a period of thermal cooling and radioactive decay is allowed, and then the air within the containment compartment will be flushed out before opening the access hatches. Thereafter accessibility will be allowed in accordance with health physics regulations.

Two access hatches are provided, large enough for the passage of personnel and replacement parts should any be required; they are situated to allow a straightforward route to all components and to give an effective airflow during flushing.

This system is provided to dispose of liquid, solid and gaseous wastes which arise in the operation of the primary system, and is designed to consume internally as much waste as possible, so that the only stored waste is spent ion exchange resin and a small amount of contaminated water. It would not be necessary at any time to discharge radioactive waste at sea, and such waste may easily be stored for discharge at a convenient time, e.g., at time of "annual" refit when disposal could be in the manner of land based practice.

Fuel Shuffling

The design of the reactor would permit operation at 80 per cent. full power for a period of about 3½ years. However, to obtain a uniform burnup of the fuel in the core, it is proposed that "shuffling" of the fuel elements should take place at 12 or 15 months' intervals during "annual" refit.

Engineering of the reactor system would be undertaken by Mitchell Engineering and the re-heat turbines and lock-train gearing by Fairfield Shipbuilding and Engineering Co., Ltd. Combustion Engineering would supply the core and control rods and also be responsible for all reactor kinetics.

G.E.C./SIMON-CARVES

Gas Cooled System

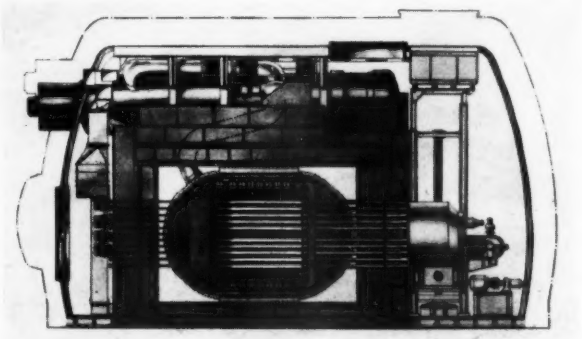
THE GEC/Simon-Carves design is based on a gas-cooled graphite-moderated reactor system in which the reactor weighs 2,400 tons and has an output of 50 MW. The fuel elements consist of slightly enriched uranium dioxide canned in stainless steel and are provided with graphite sleeves, as in other GEC reactors. The graphite core is made up of blocks held together and supported by a surrounding steel structure. The fuel-element channels extend horizontally right through the core and are interspersed with control-rod channels, also horizontal. The reactor pressure vessel is a horizontal cylindrical vessel with domed ends. Charge/discharge standpipes are at one end, and a control-rod and emergency access pipes at the other. The main gas ducts are connected through suitable nozzle forgings.

The main shielding structure surrounds and supports the pressure vessel and is made from steel plate. The construction is of an essentially cellular nature and the voids are filled with purified water to act as a neutron shield. A concrete plug is used at the charge/discharge end for the standpipes. The shielding water is circulated through an external cooling circuit.

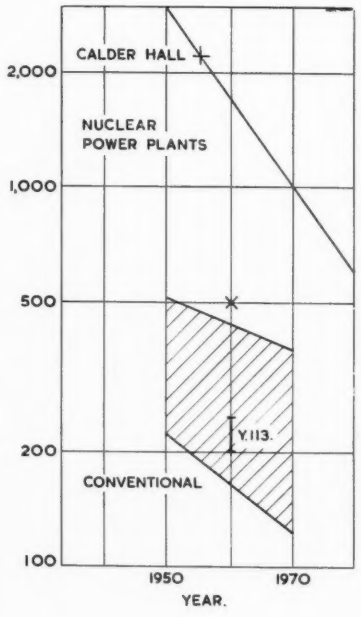
The primary coolant ducts carry the high-pressure carbon-dioxide gas coolant between the reactor vessel and the four steam-raising units. Turbine-driven circulators are mounted at the aft ends of the s.r.u. units.

The charge/discharge machine is a pressurized and shielded unit which can be connected to any one of the charge/discharge standpipes, there being one of these for each fuel channel. It is possible to charge fuel with the reactor under load and the ship at sea should this be required.

The control system consists primarily of a series of neutron absorbing tubes which can be inserted into the graphite core to



(*Above*) **Longitudinal section through the improved version of the GEC/Simon-Carves marine-propulsion reactor, with an outline of the original design for comparison. The reactor is in the centre surrounded by the water biological shield. The charge/discharge machine is on the right; standpipes lead from it to the horizontal fuel channels in the core. Control rods enter from the left. At the top is one of the four steam-raising units, with its hot gas duct**



(*Left*) **Comparison of the weights of conventional and nuclear marine propulsion units. The top line shows an extrapolation from present land-based nuclear stations, and the cross at 500 lb/h.p. a recently proposed nuclear marine installation. The lower limit of the shaded area shows the approximate trend of conventional ship-propulsion machinery, and the upper one that with the additional weight of fuel oil. The line marked Y.113 shows the original (upper) and revised (lower) weights of the GEC/Simon-Carves marine propulsion unit. All weights in lb/s.h.p.**

control the nuclear reaction. A separate emergency shut-down system is provided in the form of additional rods housed inside the normal control tubes.

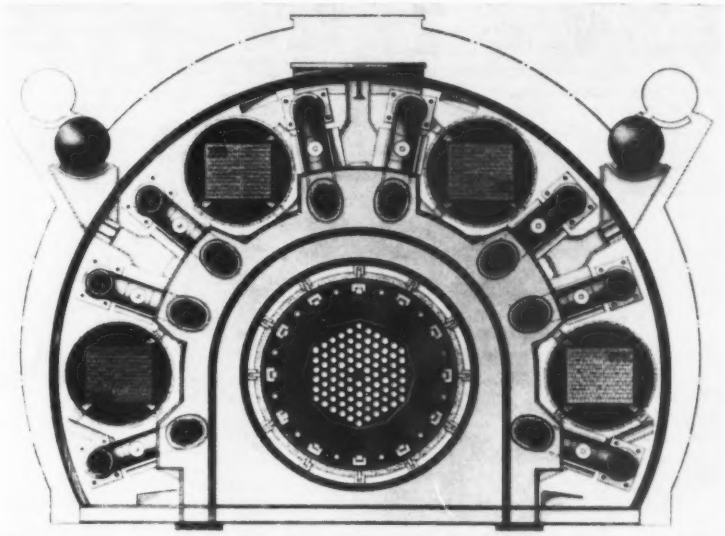
The secondary gas circuits include the CO_2 generation and storage equipment (make-up CO_2 of high purity is generated from fuel oil) and CO_2 filtration and drying circuits.

The burst cartridge detection equipment enables a continuous check to be maintained on the conditions of the fuel elements.

The containment vessel is a truncated cylindrical vessel resting on a flat grillage. It houses all the nuclear and steam raising plant with the exception of the steam drums, and has the minimum possible number of penetrations. The necessary filtration and cooling plant is supplied and integrated into the system for the cooling of the main shield water.

Personnel would not usually enter the containment vessel during normal running of the plant, although it is quite safe for them to do so if necessary.

The first reactor of this type for ship propulsion would be built for about £3m. Reduction in fuel requirements would make available additional carrying capacity of the order of 5,000 tons and costs per ton/mile carried would be comparable with those for conventional thermal plant. It is expected that, with advances in design, these costs can be cut still further.



Transverse section through the improved version of the GEC/Simon-Carves marine-propulsion reactor, with an outline of the original design for comparison. The reactor core is in the centre, supported inside the pressure vessel which is in turn supported inside the container for the water biological shield. The four steam-raising units are spaced around the outside of the shield, each with its associated hot and cold gas ducts. The ducts are curved and run inside the shield for some distance so as to prevent direct leakage of radiation from the core. The whole system is enclosed in the containment vessel, except for the steam drums which can be seen outside it

HAWKER SIDDELEY

OMR

THE Hawker Siddeley Nuclear Power Co., have submitted a design project utilizing an organic moderated reactor. It is possible to achieve with this type of reactor lower than conventional operating costs for medium size commercial ships—for instance with tankers having a tonnage of 40,000. OMR offers many advantages particularly suitable to ship propulsion. It takes up little room, it is essentially simple; the liquid coolant, terphenyl, is non-corrosive and has a low vapour pressure. These properties result in a system pressure of less than 100 lb/sq.in. and the utilization of mild steel in the construction of the reactor vessel and primary circuit. Conventional equipment may be used in this circuit and due to the lack of induced activity in the coolant, access to this circuit is possible whilst the reactor is in operation.

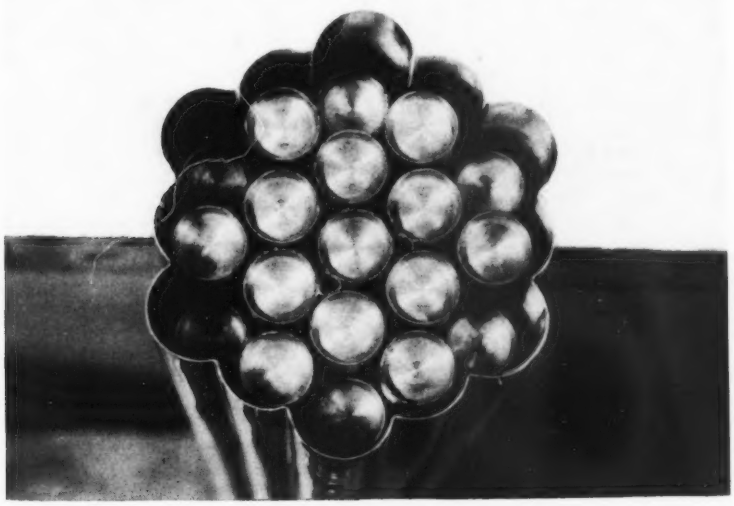
This particular reactor which has a heat output of 56 MW has been designed to utilize uranium oxide fuel elements canned in stainless steel. It was necessary to postulate that sea water might enter the reactor core as a result of catastrophic collision or sinking and the utilization of uranium oxide and stainless steel offers a very corrosion resistant combination against sea water attack. For a 17,000 s.h.p. ship the enrichment required in the uranium oxide fuel is 1.4 per cent.

The fuel elements are made up of two sections to allow for end to end fuel cycling and each element consists of a bundle of 19 fuel rods. Fuel cycling can be arranged at intervals of one to two years to suit the operator.

The Jason research reactor now under construction at Langley will be used to determine the detailed nuclear characteristics of the fuel element bundles. Jason will also be employed to evaluate the most satisfactory combination of elements for the shielding of the ship's reactor.

Detailed studies of the OMR on the company's analogue computer installation show that it has a negative temperature coefficient under all burn-up conditions and that the reactor is consequently self-stabilizing. It is expected that these control characteristics will allow OMR powered ships to manoeuvre at least as easily as a conventional ship. It will be possible to use plutonium enrichment with natural uranium when plutonium becomes available.

Of two criticisms usually levelled at the Organic Moderated Reactor one is that the moderator/coolant suffers from irradiation damage; however, the cost of replenishment is only 0.7d./s.h.p./hr. It is expected that with increasing demand for terphenyl, its production cost and consequent replacement costs will be reduced. The other



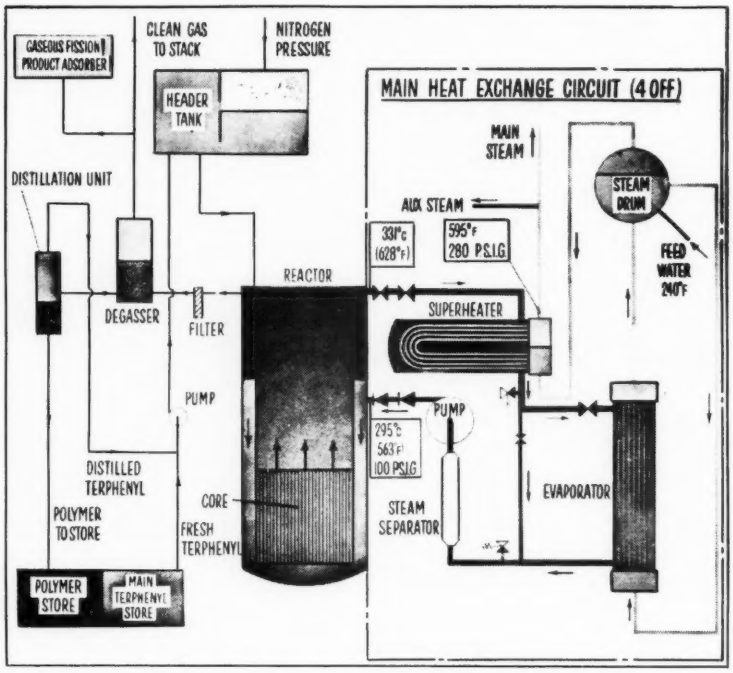
(Left) **End view of fuel element bundle for Hawker Siddeley's OMR**

criticism is that terphenyl can in certain conditions be inflammable. This can be overcome quite readily by using in the reactor compartment nitrogen-rich air, in which terphenyl cannot be ignited. This air will have an oxygen content of 15 per cent. and is breathable without the use of special apparatus.

Reducing Operating Costs

The OMR can be developed in various ways, each of which brings about a reduction in operating costs. Beryllium canning could be used for the fuel when this has been proven, and this would bring about a reduction in the fuel enrichment required. A graphite reflector can be employed and this would reduce operating costs by 2-3 per cent. A considerable improvement in cycle efficiency can be obtained by the utilization of a two-zone core whereby coolant passed through the outer lower flux zone of the core is raised to a higher temperature than that of the bulk of the coolant and this high temperature coolant is then passed to the superheater. Steam conditions of 710 F. and 480 lb/sq.in.abs. can thereby be achieved giving a cycle efficiency of 24.8 per cent. This results in a 9 per cent. reduction of fuel costs for an increase of only 2 per cent. in terphenyl replacement costs. It has been shown that high heat transfer rates, possibly up to nucleate boiling, can be achieved and this would permit increases of output in a given sized reactor of up to 60 per cent.

An installation of the type of OMR proposed to the Admiralty but having an output of 17,000 s.h.p. would cost approximately £890,000 and weigh about 1,300 tons. This latter figure compares with the weight of over 4,000 tons for boilers and oil fuel bunkerage for an equivalent conventional tanker. Operating costs for an OMR of such an output and suitable for a 40,000 ton tanker are about 5 per cent. higher than conventional operating costs. With development and plutonium enrichment, however, the operating costs of such an OMR tanker are expected to be about 5 per cent. less than those of a comparable conventionally powered ship.



Flow sheet of the Hawker Siddeley organic moderated reactor system

A.E.I.-J.T.

Direct BWR

SUBMITTED by the AEI-John Thompson Nuclear Energy Co., Ltd., is a deisgn for a direct boiling water reactor and geared turbines which can be delivered in 30 months. The reactor, which is based on experience gained by the General Electric Co., of America, has a heat output of 82 MW. Weight of the plant, including steam raising units, is 1,600 tons. Fuel is 2.1 per cent. enriched uranium made up into 3,744 elements. Weight of a fuel loading is 8.7 tonnes.

Design allows for the reactor to operate at full power without refuelling for about 380 days.

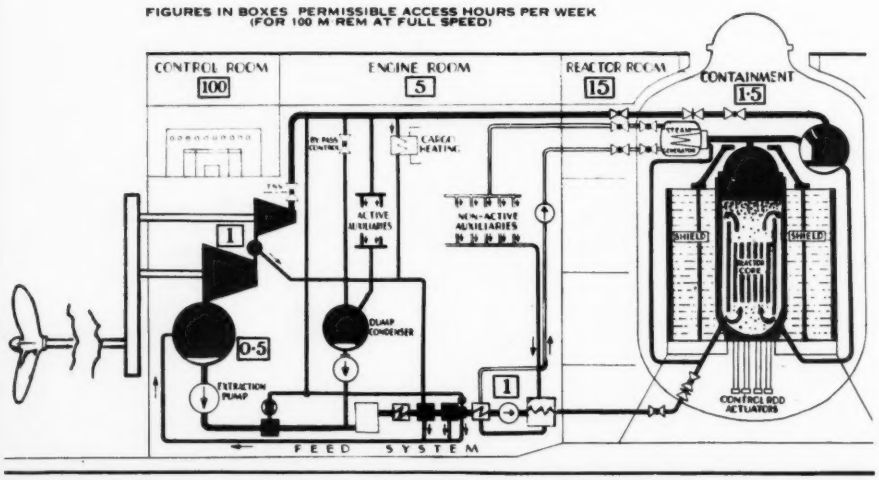
The pressure vessel with an internal diameter of 96 in. and overall height of 30 ft is designed to withstand pressures of up to 1,750 lb/sq.in. gauge and temperatures of 300°C. Maximum temperature of primary circuit will be 286°C.

Shielding consists of steel and water. Secondary shielding in engine room is 6 in. steel plate and at end of steam drums 2 in. plate.

Comparative fuel costs are given as 0.29d./s.h.p. for a ship employing this system as against 0.384d./s.h.p. for a vessel burning oil at 132s. 6d./ton.

The advantages of a boiling water reactor are said to be:—1, simplicity; 2, lightness; 3, compactness (it is claimed to be smaller than any other reactor type); and 4, ability to burn plutonium, a considerable advantage for those countries, such as Britain, with limited capacity for the production of enriched uranium.

At first the components for the reactor will be purchased from General Electric, but subsequently the entire unit will be constructed by Associated Electrical Industries Ltd., and John Thompson Ltd.



Flow diagram, side view, of the direct boiling water reactor system proposed by the AEI-John Thompson Nuclear Energy Co. It is based on experience gained by the General Electric Co., of America

De HAVILLAND

HTGCR System

THE system proposed by the De Havilland Nuclear Power Group is a high temperature gas cooled reactor design incorporating similar basic principles to those of the experimental reactor DRAGON designed by the UKAEA. The construction of this latter project (details in NUCLEAR ENERGY ENGINEER, April, 1959) is supported by the OEEC and completion is planned for the end of 1962.

Two reactors, having a total weight of 2,400 tons will be installed in tandem in the ship giving a total heat output of 150 MW. The reactors can operate independently—a considerable safeguard in the event of failure of one unit. Hatches will be required in the decking above the reactors to allow access for refuelling, but apart from this the structure can be continuous and added strength is thereby imparted to the ship.

Uranium and Thorium

The fuel used in the reactors is a mixture of U-235 and thorium in ceramic form bonded into graphite pellets. These are contained in sealed impermeable graphite blocks which give additional neutron moderation. Helium gas at a pressure of 1,000 lb/sq.in. is pumped through a large number of coolant holes in the core and transfers the heat produced to six boiler units projecting above the reactor pressure vessel. The use of an all ceramic core permits safe operation at temperatures in excess of 1,000°C. (1,832°F.) and the large temperature difference between the fuel and steam results in a high core heat rating, small boiler size, and low pumping power loss. The steam conditions (600 lb/sq.in. 850°F.) correspond to those currently used in naval machinery.

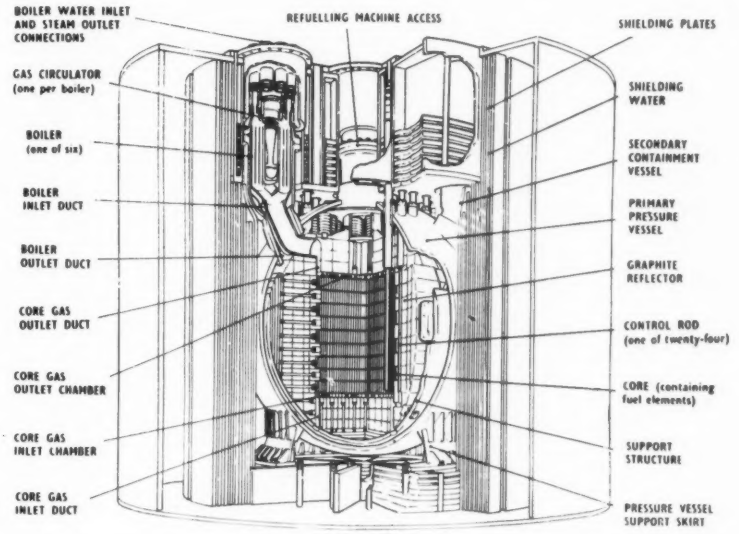
The integration of the boiler-circulator units with the pressure vessel results in a compact plant layout and enables a secondary containment vessel to be fitted inside the main biological shield. No additional shielding is necessary, therefore, to protect against leakage into the secondary containment. A laminated iron and water shield is used to reduce weight and act as a tertiary containment vessel. It also affords a considerable degree of protection to the pressure vessel in the event of a collision.

Calculations show that in the event of a complete failure of the coolant system the decay heat produced after shut-down will be adequately transferred to the surrounding structure by conduction and radiation without an excessive rise in core temperature. Further study and experimental work is required to prove this point beyond doubt.

It is predicted that refuelling will be necessary at intervals of not less than four years and there is strong evidence to suggest that much longer periods of operation may be realized. This results from the good conversion factor and the superior nuclear characteristics of the U-235 produced with this system. Radiation damage effects to the fuel are minimized by the dilute dispersion of fuel in the graphite matrix.

The system promises to be attractive both from the point of view of low capital and running costs. An estimate of the cost of the first production unit (less core fuel blocks) indicates a figure in the region of £1.4m. for a twin reactor installation (i.e. £28/s.h.p.). Low fuel cost results from a low initial investment (67 kg U-235) and the long core life.

A tentative research and development programme suggests that a prototype ship installation could be completed by the end of 1964 and the overall cost of this five-year programme would amount to about £13m. The system is considered to have considerable development potential. The power output of the reactor could be increased by increasing the pumping power, the circuit pressure, and the fuel element temperatures. The acceptance of an active primary circuit would permit the use of an all beryllia moderated core, would greatly extend the core life, and would make a period of 20 years between refuellings feasible. The use of a simple closed cycle gas turbine in place of the steam plant now proposed would reduce the specific cost of the complete propulsion system by something like £20/s.h.p.



Cutaway sectional drawing of the high temperature gas cooled reactor design submitted by the De Havilland Nuclear Power Group

VICKERS GROUP

Steam Cooled Reactor

VICKERS Nuclear Engineering Ltd., comprising Rolls Royce Ltd., Foster Wheeler Ltd., and Vickers Ltd., have submitted a design for a heavy water moderated reactor system which uses dry steam as coolant. Of all the designs submitted it is the most revolutionary. The steam is used at conventional temperatures and pressures: a self-driving steam circuit being used in preference to a pumped circuit. Any losses in coolant can be readily made up from the ship's fresh water plant, a distinct advantage.

The heavy water used as moderator is kept at low temperatures and at almost atmospheric pressures. Control of the reactor is effected by changing the level of the moderator; hence there are no moving parts in the core.

The reactor is of pressure tube design, to permit scaling of the reactor up or down to meet requirements for reactors of different outputs.

Fuel element design is simple and employs uranium oxide pellets sheathed in stainless steel cans. Low enriched fuel is used and the design is suited for the use of plutonium.

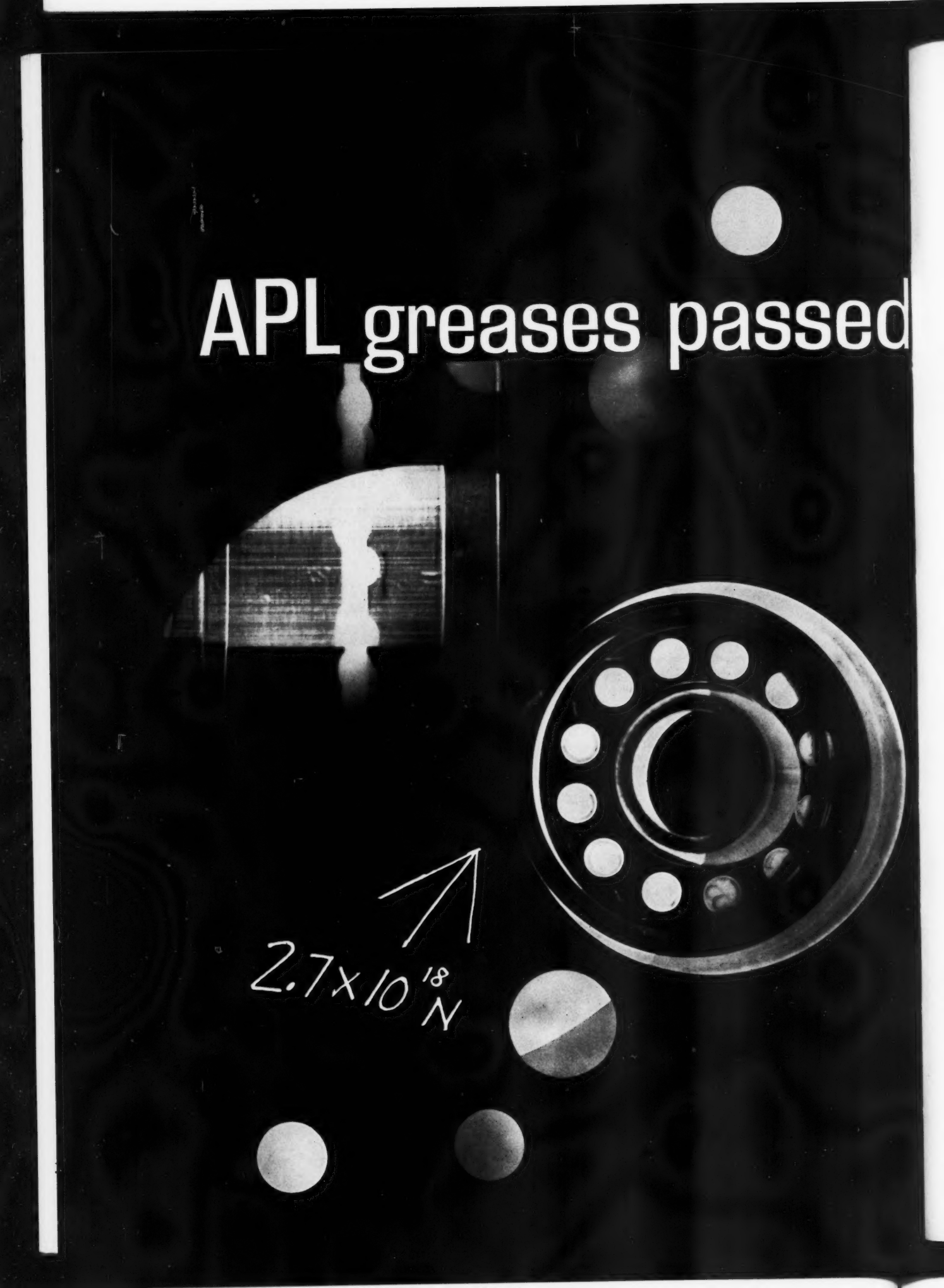
Materials used in the reactor have been chosen that will not react chemically with each other or with sea-water—UO_2, stainless steel, aluminium and water.

The equipment inside the containment shell is largely stationary. The only moving parts are outside the core and are:—canned heavy water circulating and control pumps, control and isolating valves, and primary circuit feed pumps. All have been designed to fail without immediate external control action being necessary.

In the prototype study, a secondary steam circuit with its heat exchangers is included. It is hoped, however, that open cycle operation may prove possible, resulting in a saving in weight and in the turbines

(*Continued on page 348*)

APL greases passed



the final test...

Radiation broke up the gel structure of conventional greases. They lost their lubricating properties, turned fluid or granulated. Completely new kinds of greases were needed by the atomic power industry for the bearings situated within the radiation field.

The Shell Group started working out radiation-resistant APL greases whilst most nuclear power stations were still on the drawing-board, and the research that went into them is characteristic of the way Shell set about doing things.

A team of research workers was assembled at Shell's Research Centre at Thornton. After four years of research and testing – both at Thornton and the A.E.R.E. Harwell – APL greases were ready for their finals. A sample was packed into a bearing and sunk into the B.E.P.O. pile. There it was not only subjected to mechanical working and high temperatures in CO_2, but also to an integrated pile dosage of 2.7×10^{18} thermal N. per sq. cm. plus associated radiation. APL greases sailed through their finals – and Shell are proud of it. They should be. For with these greases, Shell completed Britain's first range of Atomic Power Lubricants.

The moral of the APL story is that Shell research is supremely applicational. The Centre at Thornton is always ready to work with even the most specialised sectors of industry to produce the right lubricant for the job. If you and your organisation have any major lubrication problem, it will pay you to get in touch with your local distributor of Shell Industrial Lubricants.

The Research Story

Naturally a whole variety of greases were investigated. Conventional metallic soap greases were affected even by relatively low levels of radiation. Other greases based on synthetic and non-petroleum materials were examined and found to be equally unstable. Some of them softened appreciably and became tacky, whilst others hardened.

The Shell APL 700 series of greases are specially processed with an inorganic gelling agent, the base lubricant used being similar to the APL oils previously proved highly resistant to radiation. There were three series of tests. First tests were preliminary radiation tests at Harwell. Then the greases were tested for their lubricating qualities in a high temperature (400°F) pressurised CO_2 anti-friction bearing rig turning at 1,500 r.p.m. For the final tests, actual working conditions were simulated at Harwell.

SHELL

ATOMIC POWER LUBRICANTS

another proof of Shell leadership in lubrication

MARINE PROPULSION

(*Continued from page 345*)

operating at higher temperatures and pressures, independent of the load.

The proposed design has a high degree of inherent stability.

Weight of the plant, including containment and secondary heat exchangers, is 2,100 tons.

The reactor is wholly of British design in which existing technology has been used throughout to avoid prolonged testing and development. Vickers Nuclear Engineering have the resources to complete the design and development of the system with the exception of fuel elements testing and critical assembly work. It is hoped that the group's association with Westinghouse Electric Corporation will lead to the possibility of them working in collaboration with the American company on the development of the fuel elements.

View of the exhibit of models and drawings used by Vickers Nuclear Engineering to illustrate their novel steam cooled reactor system to the Admiralty experts. We hope to publish more details of this particular system in a forthcoming issue

U.K. ATOMIC ENERGY AUTHORITY

AGR System

THE United Kingdom Atomic Energy Authority is at present reluctant to reveal any details of the reactor system it has proposed to the Admiralty, except that it is based on the advanced gas cooled reactor concept. A prototype AGR is being built at Windscale (details, NUCLEAR ENERGY ENGINEER, February, 1959), and it is believed that the marine unit is fundamentally of the same design.

Two members of the Industrial Group of the UKAEA, R. V. Moore and C. E. Iliffe, dealt with AGR marine units in a paper presented at last year's International Conference on the Peaceful Uses of Atomic Energy at Geneva. They gave typical specifications of two possible reactors, one using magnesium alloy canned uranium metal as fuel and the other steel cermet fuel. Both units were for driving a 50,000 s.h.p. vessel.

The 14 ft diameter magnesium alloy fuelled core reactor would be housed in an 18 ft 6 in. diameter pressure vessel fabricated from 3 in. steel. Fuel elements would be made up of 18 rods of 0.3 in. diameter. Maximum fuel element surface temperature would be 450°C., outlet gas temperature 400°C., and inlet gas temperature 217°C. TSV steam temperatures and pressures would be 702°F. and 500 lb/sq.in.abs, respectively.

The other reactor would have a 4 ft 9 in. diameter core hoisted in a 7 ft 4 in. diameter pressure vessel. The fuel elements would be made up of 14 plates, 0.045 in. thick, 15 per cent. by weight of UO_2 and 85 per cent. by weight 18/8 stainless steel. Fuel element surface temperature would reach a maximum of 600°C. and inlet and outlet gas temperatures 260°C. and 480°C. Steam pressure would be 1,030 lb/sq.in.abs and steam temperature 940°C.

Important Data of Proposed Systems

	Output MW(t)	Core dimensions, ft	Pressure Vessel, ft	Steam temperature, °F.	Steam pressure, lb-sq.in.	Total weight, tons
AEI-JT—BWR	82 (50 per cent.)	6 × 5	30 × 8	546	1,000	1,600
Babcock & Wilcox—PWR	180	—	42.5 diameter	447	1,750	3,000
De Havilland—HTGCR	150	6 × 6	—	850	600	2,400 (2 reactors)
GEC/Simon-Carves—GCR	150	6.75 × 7.5	14 diameter	850	600	2,400
Hawker Siddeley—OMR (scaled down design)	56	5 × 5.2	—	710	480	1,300
Mitchell—BWR	156	7.8 × 6.8	24 × 9	538	950	3,000
UKAEA—AGR	—	14 diameter	18.5 diameter	702	500	—
Vickers—Steam-cooled	150	10 × 10	—	850	420	2,100

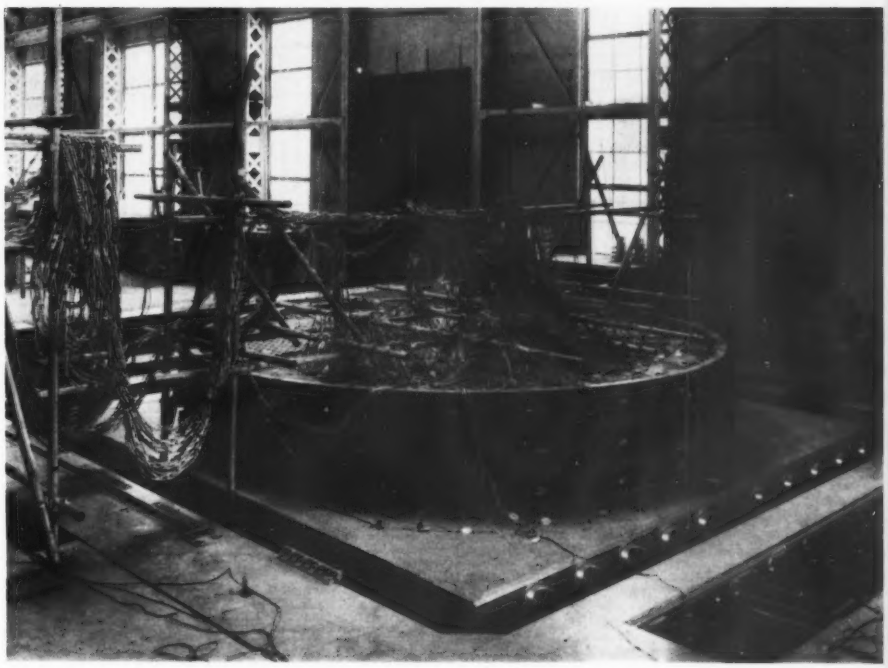
REACTOR EARTHQUAKE TESTS

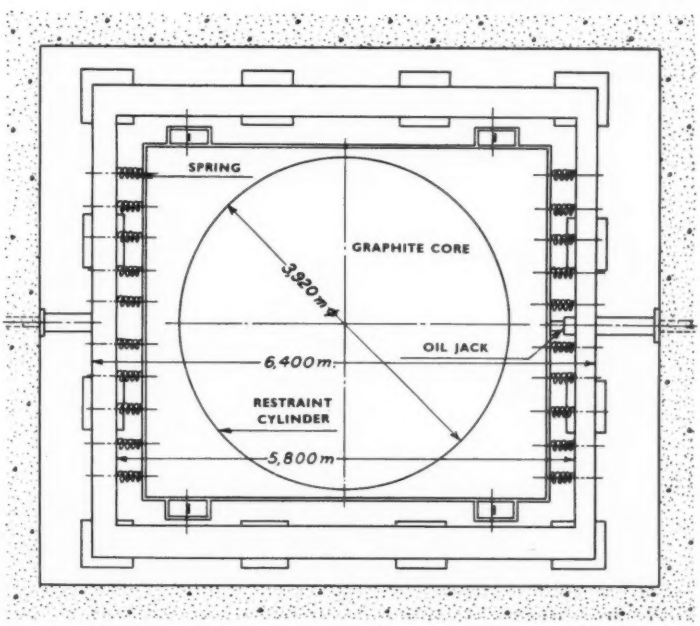
Before British proposals for a gas-cooled graphite moderated reactor for Japan's first nuclear power station were accepted, Japanese scientists carried out tests to determine the stability of a graphite core under earthquake conditions. These tests were undertaken on a specially constructed vibration table—the largest of its kind in the world—with graphite blocks one-third the size of those used in the Calder Hall reactors

NUCLEAR power stations in Japan have to be earthquake-proof: of particular importance in meeting this requirement is the stability of the reactor core. With this in mind, the Japan Atomic Power Company last year formed the Earthquake Counter-Measures Committee, comprising scientists, engineers and other experts, to study aseismic reactor designs.

Among the committee's first tasks was the appraisal of the designs for a gas-cooled, graphite-moderated reactor plant submitted by three British consortia for Japan's first nuclear power station. A sub-committee was formed and this, in collaboration with the Building Research Institute of the Ministry of Construction, built a special seismic apparatus for determining the stability of a graphite core under earthquake conditions.

The core of a graphite moderated reactor consists of layers of pillar-shaped graphite bricks separated by board-shaped graphite tiles. Its stability depends on the shape of these components and how they are fitted together. Further stabilization can be effected by introducing some means of tightening the graphite externally.





(*Above*) **View of the world's largest vibration table built specially for testing reactor core models**
(*Left*) **Plan of table**

One Third Scale

For test purposes, graphite blocks and tiles made to a third scale size of those used in the Calder Hall reactors are used.

The test apparatus is a 4.9 m long, 4.5 m wide earthquake test table. It weighs over 11 tons and is believed to be the largest of its kind in the world.

With this table it is possible to measure the displacement of the

graphite in the model pile and stresses at various points of the pile. It is also possible to discover the manner of transmission of the tightening forces and also to prove theoretical calculations.

Both static and dynamic tests can be undertaken with the table.

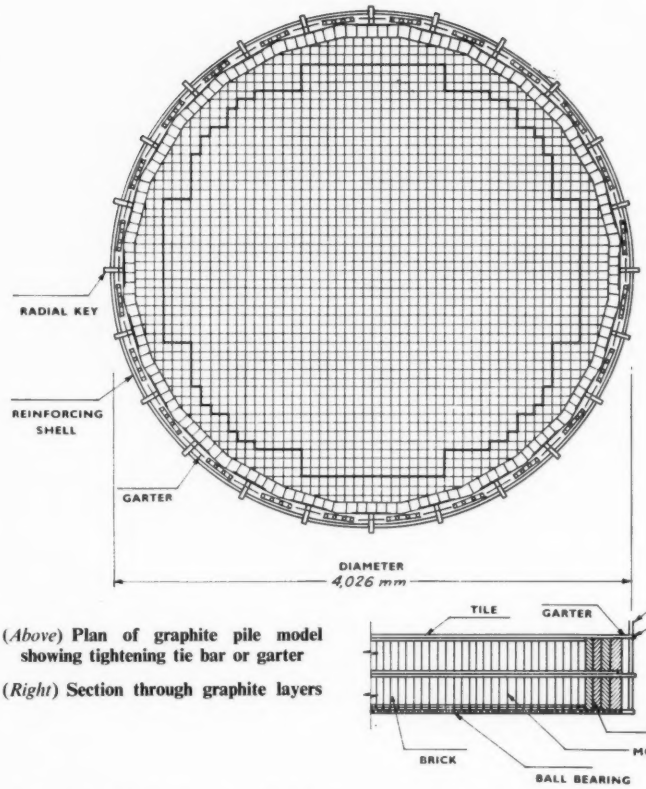
Horizontal Shocks

A static test is one in which objects on the table are tilted together with the table in order to subject the objects to a lateral force equivalent to a horizontal shock given to objects on the ground during an earthquake. The table is tilted by means of two 50-ton hydraulic rams. Maximum tilt obtainable is at an angle of 45° and maximum load the table can carry, 50 tons.

When the platform is tilted at an angle of 45°, an acceleration of 0.7g is produced. This is far in excess of accelerations produced in actual earthquakes. During the great earthquake of 1923, for instance, the horizontal acceleration produced in the ground on the hillside of Tokyo was in the order of 0.1g.

A dynamic test is one in which the table is subjected to vibrations. These are effected by displacing the 20 coil springs installed on the front and back of the table by means of a hydraulic ram and then suddenly pulling a trigger attached to the tripping gear of the springs.

By changing the number and the rigidity of the coil springs it is possible to vary the natural period of the platform from 0.96 sec. to 0.14 sec, the amplitude up to 18 cm, and the horizontal acceleration up to a maximum of 2g.



(*Above*) **Plan of graphite pile model showing tightening tie bar or garter**

(*Right*) **Section through graphite layers**

Vertical Vibrations

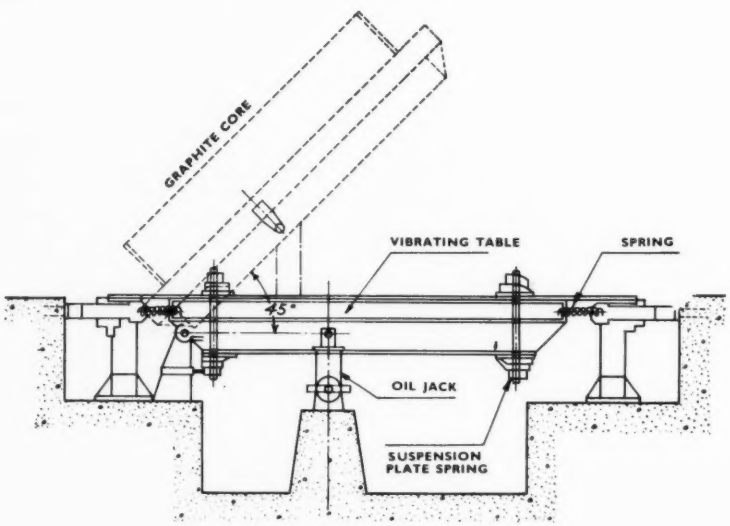
The vibration table is supported by four suspension plate springs. By slanting these springs at angles of 14° and 26.5° it is possible to produce vertical vibrations equivalent to respectively 25 per cent. and 50 per cent. of the horizontal acceleration.

Dynamic tests can be carried out with objects weighing up to 28 tons.

The model pile used in the tests consists of a 24-sided structure made up of graphite bricks and tiles. The bricks are stood up on end in two layers with two layers of tiles separating them and a third layer underneath. On top, single and double layers of tiles are used, according to the test.

The model contains about 4,500 bricks, each measuring 6.1 cm × 6.1 cm × 25 cm, and 10,000 tiles, each measuring 6.9 cm × 6.1 cm × 1.2 cm. Overall size of the structure is 3.73 m in diameter and 57.2 cm in depth.

Support is provided by bearing plates and balls.



Cross-section through vibration table

Tightening the Pile

The pile is tightened at the tile layers by means of restraint beams and bands (called garters or tie bars). The middle of the restraint bars are fitted with keys which are connected to the external reinforcing steel cylinder (diameter 4.03 m).

Tightening is effected by two methods—the radial compression

spring method and the radial shear key system.

Manufacture tolerance of the graphite is 2/100 mm. Its ultimate compressive strength is 270 kg/cm², along grain, and 240 kg/cm², across grain. Young's Modulus is 106,700 kg/cm², along grain, and 89,400 kg/cm², across grain.

Initial Tests

The first tests carried out with the model were to investigate the distribution of the tightening force on the graphite. Electric resistance gauge wires were connected to the graphite at 300 different places and a tightening force of up to 3.2g applied. By measuring the stresses exerted the manner of distribution and transmission of the force was calculated. The test was applied to the model topped first with two layers of tiles and then with only one.

Static tests involved the tilting of the model with the table at angles of 45° (to give a lateral acceleration of 0.71g) and 15° (to give a lateral acceleration of 0.26g). By this means it was possible to measure the force to be imposed on the supporting structure, the deformation of the graphite, the stress to be exerted on the pile, and the variation in tensile force of the band.

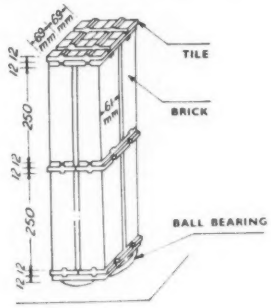
Dynamic tests enabled acceleration of the graphite and the platform in motion to be measured, and also the force to be imposed on the supporting structure and stress to be exerted on the tiles.

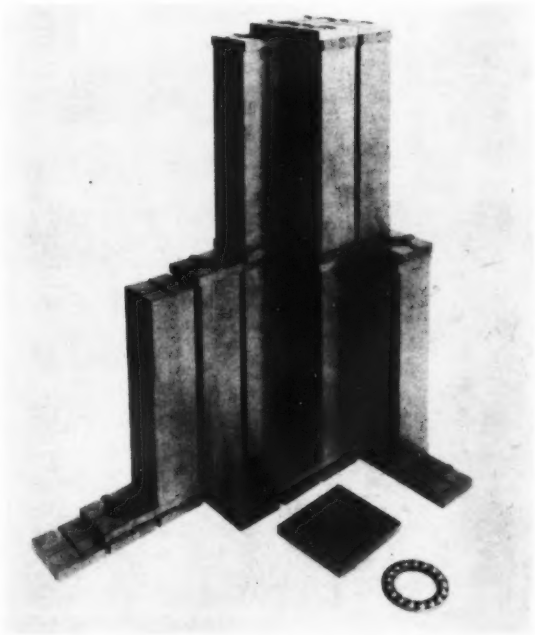
Centre Unaffected

From these tests it was found that if the graphite bricks and tiles were arranged in the same manner as they are in the Calder Hall reactors, the centre of the pile remained unaffected by any force exerted by the external tightening band. This was due to the arch action of the graphite blocks located in the circumference of the pile.

For the tightening band to have any effect in the centre, gaps had to be left between the graphite bricks. This was found to be successful whether there were two or only one layer of tiles on top of the pile.

With the graphite blocks suitably separated and tightened, the structure was subjected to more static and dynamic tests. The table was tilted





(Above and left) **Graphite tiles and bricks as used in the model, together with bearing plates and balls upon which the graphite pile rests**

View of vibration table and model reactor core during a test

at an angle of 45°, to produce a lateral acceleration equivalent to 0.7g, and vibrations set up to produce a horizontal force of 0.7g and vertical force of 0.38g. The tremors simulated had an accumulated amplitude of about 6 cm.

Nothing unusual happened in the pile, such as buckling of the tiles or mutilation of the graphite. Neither was the graphite subject to any great deformation during the static tests. The pile moved as a monolithic body.

Theory Confirmed

The amount of movement of the graphite pile, the force imposed on the radial keys and the distribution of the stresses on the graphite tiles obtained during the experiments were found to agree with the values obtained by calculation. That is to say, the amount of movement of graphite was confirmed to be 2 mm under a lateral force of 0.7g. and stress values were found to be far less than the ultimate strength values.

The tests confirmed that provided a proper supporting structure was used a suitably designed graphite reactor core could stand up to earthquakes without there being fear of collapse or deformation of the graphite which would prevent the entry of the reactor control rods.

Safety of the reactor against earthquakes is assured.

ONE of the latest British medical irradiation units using a cobalt source was unveiled recently at Nottingham General Hospital by Sir Stanford Cade, the well-known surgeon and vice-chairman of the executive committee of the British Empire Cancer Campaign. The Mobaltron at Nottingham is one of many now being supplied to British and European hospitals by Nuclear Engineering, Ltd., Greenwich, a subsidiary of G. A. Harvey & Co. (London), Ltd.

LUBRICANTS in Nuclear Power Stations

by

H. C. O'Connor, BSc, PhD, AMIMechE

IN an article about lubrication in nuclear power stations it is convenient to distinguish between the steam raising plant of the power station and the generating plant. By steam raising plant is meant the reactor and associated fuel handling equipment, and the gas circulating plant. By the generating plant is meant all " conventional " plant such as turbo-generators and their necessary auxiliaries.

Lubrication practice, as applied to the last-mentioned items of plant, follows the practice applied to coal- and oil-fired stations. In general, at present no special problems or difficulties that cannot be resolved by the sort of development and improvement which is continuously undertaken by the major oil companies. In this field the most recent important advance has been the development of multi-purpose lithium based greases incorporating anti-oxidants and, necessary, extreme pressure additives.

Reliability Vital

By their nature, nuclear power stations are intended for use as base load stations. This implies long periods of continuous troublefree running of steam raising plant. This in turn demands relatively tight maintenance schedules which are already affected by health safety regulations. Thus, equipment and, therefore, lubrication must possess, above all, the attribute of general reliability.

As with any large installation, effective operation depends on correct functioning of a number of items of plant. Hence, it is invidious to select any particular piece of equipment as being of greater importance than the rest. This is not to say that the problems are the same for all items of equipment; for example, in nuclear power stations one group of difficulties centres around the charging and control mechanisms, both inside and outside the reactor. A second difficulty arises in the provision of a suitable lubricant for the blowers which circulate the coolant.

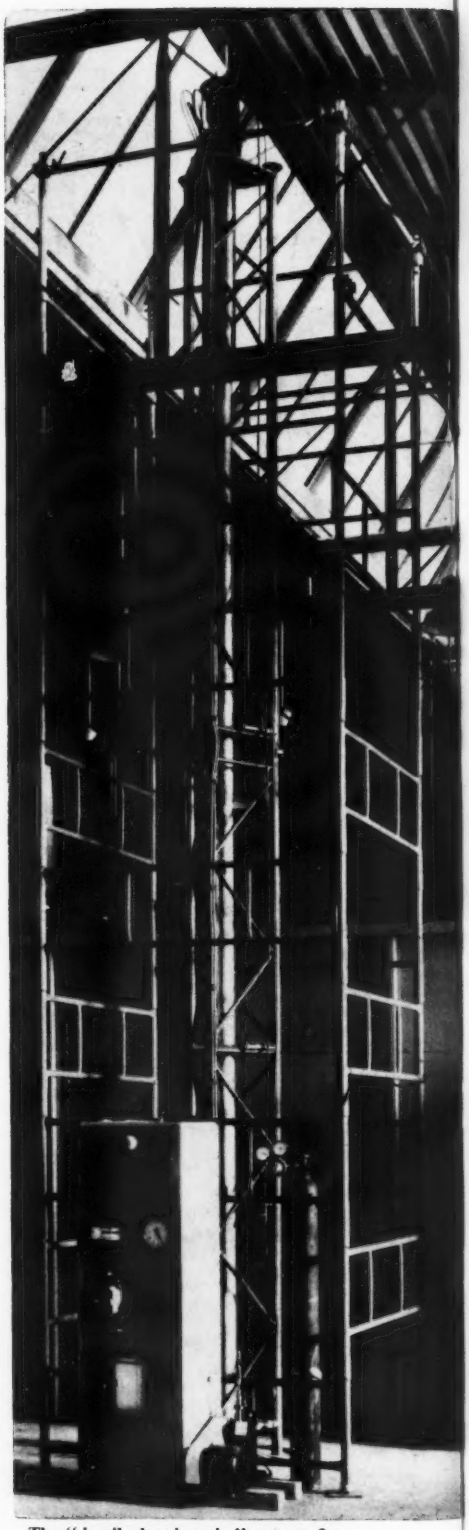
Initial Research General

Under present design concepts, as applied to gas-cooled/natural uranium reactors now under construction in this country, the fuel charging machine operates immediately over or under and in contact with the reactor in an irradiated atmosphere of CO_2 at pressure in excess of 100 lb/sq.in. and at temperatures which may be as high as 200°C. Control rod mechanisms are also exposed to CO_2 at high temperatures and pressure, but are not subject to such a high level of radiation intensity. Items to be lubricated include ball and roller bearings, gears, sleeves, and sliding surfaces generally. Generally, speeds and loads are low.

Long before any detailed designs were made it was apparent that a new range of oils and grease would be required. At the time no information of any kind was available concerning resistance to irradiation of petroleum hydrocarbons or silicone fluids in use as lubricants. A programme of research, based on general considerations, was therefore planned.

Co-60 Source Used

As a first step, a range of samples of hydrocarbon mineral oils having widely different characteristics were subjected to irradiation in BEPO at Harwell. Immediate results demonstrated the desirability of a much more detailed investigation and a cobalt-60 source of gamma radiation was installed at the Shell Research Centre, Thornton, Ches. After irradiation experiments to check that similar effects occurred under gamma



The " in-pile bearing rig " set up for investigating the suitability of lubricants in reactor components. With this rig the lubricants were tested inside BEPO at Harwell

ray and pile irradiations, a full programme of work was begun.

The nature of this work and its results are published elsewhere[1]. Briefly, it was found that under nuclear radiation hydrocarbon oils undergo complex changes which result in increases in viscosity. These increases vary for a given dosage according to the composition of the oil. If irradiation is continued until it reaches the order of 10^{18} neutrons/sq.cm, solidification occurs with some oils. Oils of higher viscosity are less stable than oils with lower viscosity, and oils essentially paraffinic in nature are less stable than naphthenic oils. Some aromatic additives confer slight protection to hydrocarbon oils. Hydrocarbon oils as a class are relatively more stable towards radiation than synthetic fluids, including silicone oils, examined.

Not The Be All

From these results it was apparent that, by careful selection and suitable treatment, hydrocarbon lubricating oils, which would withstand relatively high dosages, could probably be produced.

However, resistance to radiation, though a basic requirement, does not necessarily mean that the oil concerned has the properties necessary that render it a good lubricant. The principal cause of deterioration of mineral oils as commonly applied is oxidation. It has been established in radiation experiments that excessive oxidation did not occur, so that this particular problem is no different with the new lubricants than older ones. Further requirements of any new oils are specific to their functions; for example, high viscosity oils are necessary for slow moving gears; hydraulic oils require anti-foam and anti-rust properties, and so on.

For Specific Needs

All of these aspects were borne in mind during development. As a result there now exists a range of oils, each having different viscosity, together with a series of oils having particular attributes which render them suitable for special application: hydraulic fluid is one example. These oils can be used at radiation dosages up to 1.6×10^{18} neutrons/sq.cm.

The need for a range of suitable greases, from the nature of the mechanisms envisaged and their operating conditions, was more pressing than the need for oils. Radiation experiments on greases, therefore were conducted at the same time that oils were examined.

Soap-based greases are essentially oils held in a matrix of soap crystals. The most successful grease now marketed has as its base lithium hydroxystearate; most widely used for many years, however, has been sodium-based grease. Experiments showed that greases formed with differing base oils, using either lithium or sodium soap, suffer marked and deleterious changes under relatively low levels of irradiation. With both types of soap the greases become fluid when hydrocarbon oil is used. Apparently, a significant breakdown in the soap structure is caused: with silicone fluid in place of mineral oil hardening may occur.

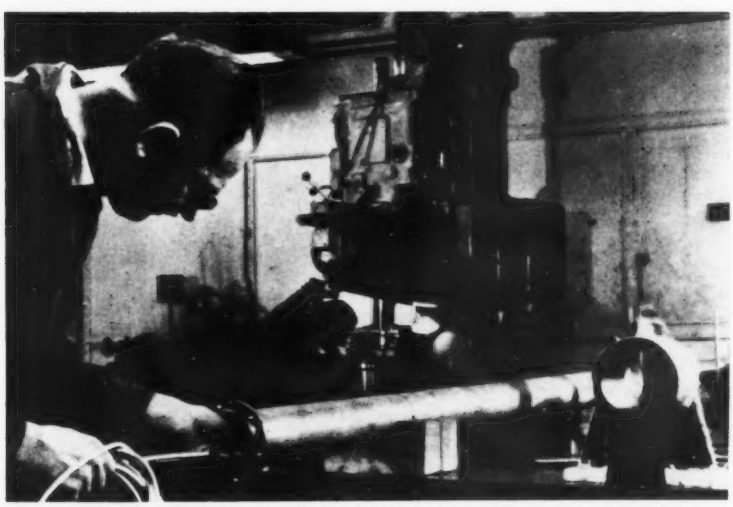
A grease rendered fluid by radiation would escape from its point of application and cause contamination of the reactor. Apart from this problem, there were still the difficult conditions of an atmosphere of CO_2 at high temperature and pressure to contend with.

Greases were developed at Thornton which were not based on metallic soap. The best one of these greases, from the radiation resistance requirement shows no physical change at a radiation dosage higher than the recommended maximum for the range of lubricating oils referred to above.

Harwell Rig

Properties of this grease as a lubricant for anti-friction bearings were proved in long term rig tests, in which packed bearings were subjected to atmospheres of CO_2 at high temperature and pressure. In addition, the performance of the grease in the combination of all conditions to be met with in the reactor was

(*Continued on page 356*)



Construction of the 22 ft long " in-pile bearing rig." One end of the rig contains a bearing lubricated with the experimental product, the bearing being run inside BEPO for periods of 2-3 weeks

The Author

Dr. H. C. O'Connor was educated at Cambridge and Bristol Universities and graduated with first class honours in mechanical engineering. He was awarded a doctorate for studies on the fatigue properties of alloy steel. After a period as lecturer in engineering at the University of Sydney, Australia, he was appointed to Lubricants Department, Shell-Mex and B.P. Ltd., where his principal responsibilities are concerned with lubricants and insulating oil applications in power stations

Research on

ATOMIC LENGTH STANDARDS

Two promising approaches for improving length standards are under study at the National Bureau of Standards. These are the atomic beam and the Zeeman absorption filter. Both have proved successful in producing very narrow lines whose wave lengths can be precisely determined

ATTEMPTS to define the basic unit of length, the metre, in terms of an unchanging property of nature have been under way for many years. The present standard, the distance between two engraved lines on a platinum-iridium bar, not only lacks the reproducibility and availability that a standard as fundamental as length should have, but, being material, it can be altered or destroyed. As early as 1892, Michelson attacked this problem by measuring the metre in terms of a wave length of light.

This same approach forms the basis for the presently proposed international standard, the orange line from krypton-86. Sources making use of this isotope can furnish standards which should be reproducible to 1 part in 10^8—a great improvement over the precision obtainable with the metre bar. However, to keep the standardizing laboratories of the various countries well ahead of the requirement of science and technology, the development of more precise standards must continue. Furthermore, the problems involved in utilizing this precision in the calibration of material standards must be solved.

Isotopes Limited

The precision of a wave length standard depends on the measureability of the line used. Kr86 lamps produce radiation whose wave length can be measured to a part in 60m.—very nearly the best result possible with a discharge tube source. As little further improvement can be expected with the use of other isotopes in discharge tubes, an entirely different line of attack must henceforth be adopted in the search for more precise length standards.

In investigating methods of producing an improved wave length standard of length, the National Bureau of Standards has found two promising approaches. One is the atomic beam, which can be used as either an emission or an absorption source, and the other is the Zeeman absorption filter. By producing extremely narrow spectral lines, both of these approaches can increase precision far beyond that presently required by research and technology.

The precision possible with present standards is limited by Doppler broadening of spectral lines—an effect due to the random motion of the emitting atoms towards and away from the observer. K. G. Kessler, R. L. Barger, and W. G. Schweitzer, Jr., of the Bureau's length laboratory, and K. W. Meissner of Purdue University, have found a successful solution to this problem in atomic-beam devices[1].

Atomic-beam techniques, developed many years ago for the study of hyperfine structure in atomic spectra, decrease Doppler broadening by selecting atoms travelling at right-angles to the line of sight. The drawback here, however, is that the light intensity is very low because the device must be operated at low densities to avoid collisions between atoms and to maintain a collimated beam. Even so, the atomic beam has proved satisfactory in both emission and absorption devices for producing very narrow spectral lines.

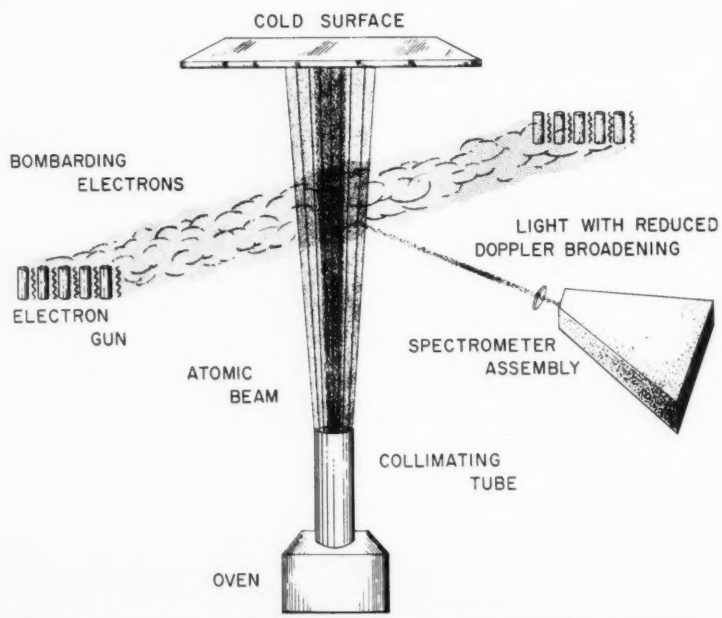


Fig. 1.—Schematic drawing illustrating the atomic beam principle used to produce narrow emission lines for atomic length standards research

Mercury Atoms Used

In an atomic-beam device used as an emission source, the atom to be excited—mercury in the Bureau studies—is heated in an oven to a temperature of about 105°C. corresponding to a vapour pressure of about 0.5mm. Atoms emerge from a slit in the oven and those that are travelling in the desired direction pass through a collimating slit and into the interaction region. Those atoms that are not travelling in the

proper direction are condensed on the walls of the collimating tube, which is immersed in a bath of liquid nitrogen.

As the atoms pass through the interaction region, they are subjected to an intense electron bombardment. Those atoms excited by the electrons emit radiation, which is observed in a direction normal to their motion thus reducing Doppler broadening.

Typical Result

Typical of the results obtained in this way is a Fabry-Perot interference pattern of the 2,537A line from a natural mercury beam source showing a half-width of $0.006\,cm^{-1}$ at a path difference for successive beams of 44 cm. If allowance is made for the broadening of the instrumental width, the emission-line width appears to be about $0.002\,cm^{-1}$. At longer path differences, the effect of the instrumental width of the interferometer becomes relatively less important and the line half-width can be more directly measured. If the position of the maximum for such a line were measured to one-fiftieth of its half-width, the resulting precision would be 1 part in a 1,000m.

(*Above*) **Equipment for producing effective narrow beams by the atomic beam method. Atoms emerging from heated mercury cell (in oven below white box) are collimated by slits cooled with liquid nitrogen. The resulting atomic beam is excited by an electron bombardment**

(*Below*) **The Zeeman absorption filter developed for producing narrow emission lines consists of a mercury cell suspended between the poles of an electromagnet. The transmission characteristics of this cell are affected by the field which causes Zeeman splitting of the absorption lines**

Another approach to the problems is to use the atomic beam as an absorption device by passing a beam of light through it. The atoms in the atomic-beam vapour absorb energy at wave lengths in the vicinity of their resonant transitions. Because the absorbing atoms are in an atomic beam, the absorption line is extremely narrow, corresponding to the projected Doppler width. Absorption lines as narrow as $0.002\,cm^{-1}$ have been produced in this way. Even though an absorption line is much less satisfactory than an emission line in interferometry, it is still in many ways an ideal wave length standard since it is produced by photon interactions and includes no other perturbations.

Successful Application

An absorption beam can be applied very successfully as a selective detector to produce an improved wave length standard. As such a detector is sensitive to only a very narrow band of wave lengths, employing it to

observe a moderately well-defined line is, in effect, the same as using a broad-band detector.

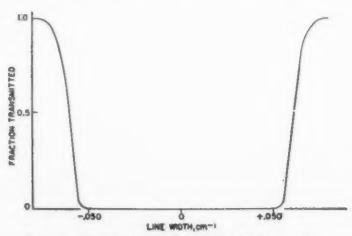
Zeeman Method

Another means for producing very narrow lines is the Zeeman absorption filter recently developed at the Bureau by Kessler and Schweitzer[2]. The action of this optical filter depends on the Zeeman effect—the splitting of spectral lines in a magnetic field.

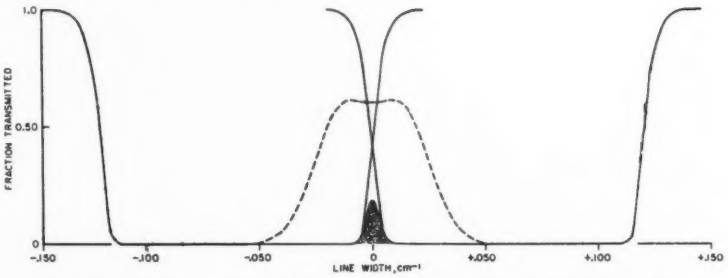
The Zeeman absorption filter designed at the Bureau consists essentially of a 1 in. long cell containing a drop of Hg198. Heating this cell to 80°C. produces a fairly thick layer of mercury atoms, which, of course, absorbs radiation most strongly in the vicinity of its resonance lines. Transmission characteristics show that this particular cell almost completely absorbs the radiation of a Hg198 lamp at 2,537A.

When the absorption cell is placed in a magnetic field normal to the direction the light travels in the cell, the absorption curve is radically altered. Light which is polarized parallel to the magnetic field experiences essentially the same absorption as without the field—practically all light of this polarization is absorbed. Light which is polarized in the other direction, however, is absorbed in a manner directly dependent on the field. As the magnetic field is applied, the broad absorption curve appearing at zero field splits into two curves, one moving toward the shorter wave lengths and the other moving by an equal amount toward the longer wave lengths. With a field of about 900 gauss, the two curves are sufficiently separated so that they just partially overlap. Between the absorption curves there is a narrow transmission region.

When light from a Hg198 lamp is passed through such a cell, the width of the 2,537A line is considerably reduced. The absorption



The transmission characteristics of a vapour of mercury atoms in the vicinity of its resonance lines



Graphs illustrating the splitting of absorption curve by means of a magnetic field. At 900 gauss the curves overlap, as shown by the solid lines. If light from a Hg 198 lamp, whose spectral distribution is shown by dashed curve, is passed through the vapour, then the transmitted radiation is the produce of the two shifted curves, represented by shaded area

characteristics of the cell act as a filter, and radiation is passed only by the region where absorption does not occur. Instead of the normal width at half-height of 0.050 cm^{-1}, a mercury line which is 0.006 cm^{-1} wide is thus obtained. This line is one-half width (0.012 cm^{-1}) of the proposed Kr86 international standard of length.

References

[1]KESSLER, K. G., BARGER, R. L., SCHWEITZER, W. G., Jr., "Atomic-beam sources and the standard of length," *Trans. IRE* (in press), and "Mercury atomic beams for metrology," *Proc. Symposium on Interferometry*, National Physical Laboratory (1959) (in press).

[2]KESSLER, K. G., and SCHWEITZER, W. G., Jr., "Zeeman-split absorption lines as very narrow pass filters," *Journal Optical Soc. Amer.*, 49, 199 (1959).

LUBRICANTS

(*Continued from page 353*)

proved in a special test rig known as the "In-Pile Bearing Rig."

This rig consisted of a closed system comprising two concentric aluminium tubes 22 ft long. A ball bearing was mounted at one end of the tubes and the inner race was rotated at 1,500 rev/min. CO_2 under pressure was pumped through the inner tube to the bearing and returned along the annular space between the tubes. The bearing end of the rig was inserted into the centre of the BEPO pile at Harwell and the bearing run for periods of 2-3 weeks. Many tests of this nature, and tests of part assemblies to be used in nuclear reactors, established without question the suitability and performance of these lubricants in charge machines and control rod mechanisms.

A further problem in lubrication arises in provision of a suitable oil for the blowers used to circulate carbon dioxide through the reactor and heat exchangers. The requirement here is for an oil of very low vapour pressure in order to minimize the possibility of contaminating the carbon dioxide with hydrocarbon vapour; of very low solubility for CO_2 in order to avoid gas leakage by solution in oil and subsequent release when pressure of the oil is lowered; of good oxidation stability; and of good corrosion resistance.

The problem of producing a suitable oil for this application is different from those already discussed in that there are no overriding considerations concerning radiation. In fact, after considerable work it was possible not only to produce an oil with a low vapour pressure and low gas solubility but a new oxidation inhibitor of low volatility was developed, and the grade in use for this application compares favourably with high quality turbine oils.

To conclude, the existence of lubricants which will withstand the difficult environments to be met and still reduce friction and prevent wear, greatly affects the complexity and, to some extent, the reliability of mechanisms designed to perform some specific functions. The general problem is of interest because it is an example of design in which lubrication assumes a much greater importance in the earliest considerations than is generally the case.

Problems of lubrication which have arisen in the nuclear power stations now being erected have been solved. The further problems which will arise when more advanced designs are used will probably centre around more severe environmental conditions.

Reference

[1]DAVID, V. W., and IRVING, R., "Effects of radiation on hydrocarbon oils, greases and some synthetic fluids." Conf. on Lubrication and Wear, Oct., 1957. Inst. Mech. Engs.

Effect of Irradiation on Fuel Materials*

PART II

by J. H. Kittel and S. H. Paine

Argonne National Laboratory, Lemont, Illinois

(*Continued from page 305*)

URANIUM-BASE alloys for low enrichment thermal reactors will generally have the crystal structure of alpha-phase uranium, since they will normally contain only small additions of alloying elements. Furthermore, these elements must be limited to those with low thermal neutron absorption cross sections. Fast reactors, on the other hand, can tolerate much greater amounts of alloying elements, so that use can be made of gamma-phase uranium alloys.

Alpha-Phase Uranium Alloys

1. Uranium-Chromium. The addition of chromium in small amounts as a means of stabilizing uranium against irradiation-induced dimensional changes was first suggested by workers at Knolls Atomic Power Laboratory. The transformation kinetics in low-chromium alloys have been reported by White[4]. Based on this information a series of 0.1 and 0.4 wt. % Cr alloys were prepared by Knolls and irradiated by Argonne.

The specimens were heat treated prior to irradiation by first isothermally transforming them at 580°C. and then again at 500°C. The 0.1 wt. % Cr specimens elongated under irradiation at about the same rate as beta-quenched uranium, although they maintained a much smoother surface. The 0.4 wt. % Cr alloy was less stable and showed surface roughening after burnups as low as 0.1 at.%. Cast eutectic alloy (5 wt. % Cr) was irradiated to burnups ranging up to 0.65 at. %. The specimens were severely damaged by surface roughening, indicating an undesirably large grain size

2. Uranium-Molybdenum. Work at Argonne has included compositions in the range of 1 to 3.5 wt. % Mo. Powder compacts, wrought material, and castings have been irradiated at moderate temperatures to burnups ranging up to 0.5 at. %. It was found that cold-pressed and sintered compacts elongated under irradiation at about the same rate as beta-quenched uranium, and that the surface roughness which developed diminished with increasing molybdenum content.

Compacts prepared by hot-rolling in a steel sheath elongated more rapidly, unless about 4% porosity was left in the compact. For example, hot-rolled compacts with 3.5 wt. % Mo and 4% porosity showed a growth coefficient of about 1.5, whereas similar full-density compacts showed an average growth coefficient of approximately 20. Irradiation growth of the wrought material was very sensitive to heat treatment. Thus, swaged 2.5 wt. % Mo alloy quenched from the gamma phase showed a growth coefficient of about 20, whereas similarly exposed material that had been slowly cooled from the gamma phase had a G_1 value of only about 4. Castings of this alloy had a growth coefficient of about 3.

3. Uranium-Plutonium. Irradiations were made on specimens of both cast and extruded binary alloys. The cast specimens included alloys of uranium with 3.7, 6.6 and 13.0 wt. % plutonium, and the extruded specimens included alloys of uranium with 9.5, 14.1 and 18.7 wt. % plutonium. One-half of the extruded specimens were given a heat treatment consisting of heating to 645°C. and cooling to and holding at 500°C. for 1hr in an attempt to remove the preferred orientation that was anticipated from extrusion. The specimens were irradiated to burnups ranging up to 0.84 at. % with central temperatures ranging up to 490°C.

The cast specimens were all found to have developed severe surface roughening as a result of the irradiation they received, presumably because of excessively large grain sizes present before irradiation. Identically fabricated unalloyed uranium showed similar behaviour. The cast specimen irradiated at the highest temperature, 440°C., was found to have increased considerably in volume. It is believed that the specimen swelled because of nucleation and growth of bubbles of volatile fission products, as has been observed in other metallic fuel materials at comparable temperatures.

The as-extruded alloy specimens maintained good surface smoothness under irradiation, but showed elongations which were markedly dependent on plutonium content. For example, in material with 0.4 at. % burnup, a 14.1 wt. % plutonium alloy specimen elongated 96%, whereas an 18.7 wt. % plutonium alloy specimen elongated only 8.4%. However, identically fabricated unalloyed uranium specimens were found to shorten under irradiation. It appears, therefore, that the amount and type of preferred orientation in extruded uranium-plutonium alloys in the range of at least 10 to 20 wt. % plutonium depends upon the plutonium content, and that it differs considerably from that in extruded unalloyed uranium.

The extruded heat treated specimens did not elongate anisotropically, indicating that the heat treatment used was effective in randomizing the grain orientation. However, the heat treatment caused an undesirably large grain size in the specimens, as

Paper presented at the 2nd International Conference on the Peaceful Uses of Atomic Energy, Geneva, 1958

evidenced by severe surface roughening resulting from irradiation.

4. Uranium-Silicon. Most of the irradiation experiments at Argonne have dealt with the composition U_3Si, which is referred to by most investigators as the epsilon phase and which contains 3.8 wt. % silicon. This alloy is highly corrosion resistant in hot water when fully converted to epsilon, and, as it is also thermodynamically stable, might be expected to retain its corrosion resistance when subjected to irradiation. Both cast and extruded epsilonized U_3Si specimens were irradiated. The cast specimens showed excellent surface smoothness and dimensional stability, with G_1 values ranging from approximately —3 to +4. However, one cast specimen, irradiated to approximately 0.8 at. % burnup at a temperature calculated to be near 600°C., increased in diameter by 33%. On attempting to make a transverse section the specimen fractured. Approximately 60% of the cross sectional area was occupied by a central void. Metallographic examination of the metal surrounding the void disclosed only a few scattered pores, in contrast to the appearance of the swelled uranium specimen shown in Fig. 12. The radial temperature gradient during irradiation of the swelled U_3Si specimen is calculated to be on the order of 1,300°C./in. The extruded U_3Si specimens displayed the same excellent surface stability as did the castings, but elongated with growth coefficient of about 30.

The effect of irradiation on the aqueous corrosion resistance of U_3Si has been measured by Greenberg[5]. He found that the irradiated alloy eventually fails in water at 315°C. by a process of mechanical disintegration, rather than by chemical dissolution.

5. Uranium-Zirconium. From experiments it was found that the dimensional stability of castings of U-1.62 wt. % Zr alloy was found to depend strongly on the irradiation temperature. Fig. 13 shows a group of specimens irradiated below 350°C., and illustrates that little change resulted from the exposure they received. The specimen with the highest burnup elongated 6.3%, with a growth coefficient of 3.8.

Figure 14 shows two additional specimens irradiated above 600°C.

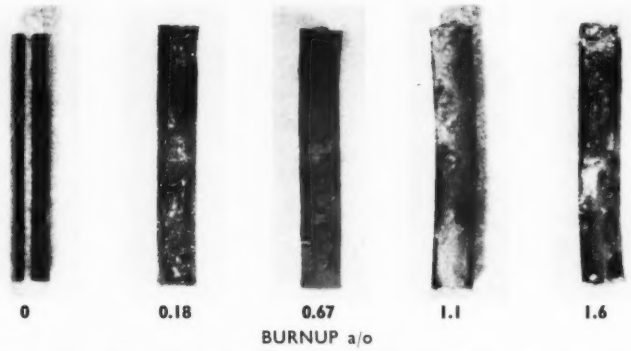


Fig. 13—Effect of irradiation below 350°C. on cast uranium-1.62 wt per cent. zirconium alloy

which exhibited large volume increases. Each of the two specimens was sectioned and found to contain a large central void, as was observed in the swelled uranium and U_3Si specimens described earlier. In this case, the metal surrounding the void was extremely porous. The radial temperature gradient in this specimen during irradiation was calculated to be on the order of 2,000°C./in.

Studies were also made on wrought uranium-ziconium alloys, principally U-2 wt. % Zr, in an effort to develop heat treatment procedures that would provide the same dimensional stability exhibited by the castings. Observations were also made of the effects of the heat treatments investigated on microstructures, hardnesses, and thermal expansion coefficients[6].

It was found that whereas the dimensional stability of wrought material could be improved if it were quenched from the gamma phase, the best stability could be obtained only by allowing the alloy to isothermally transform to the alpha phase. For example, quenching from 800°C. reduces the growth rate of as-swaged U-2 wt. % Zr specimens from $G_1 = 470$ to $G_1 = 64$, whereas tempering at 690°C. for several hours after quenching further reduces the rate to $G_1 = 3$. The growth tendency of rolled U-1 wt. % Zr and U-2 wt. % Zr alloys annealed for 48 hr at 575°C. was found to differ markedly from the behaviour of swaged material, and to be affected by carbon content. Thus, alloys with 20 ppm carbon were found to shorten at a rate such that G_1 equalled approximately —300, with 400 ppm carbon, G_1 equalled approximately

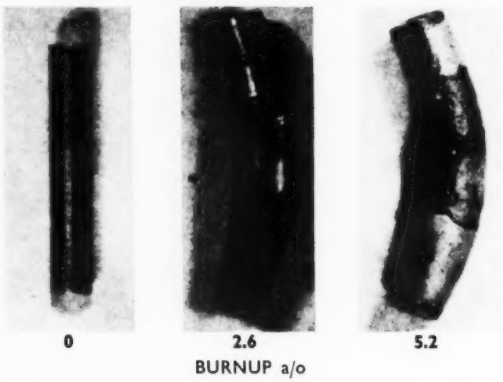


Fig. 14.—Effect of irradiation above 600°C. on cast uranium-1.62 wt per cent. zirconium alloy

— 200, whereas with 4,000 ppm carbon the alloys elongated, with an average value of $G_1 = 150$.

6. Uranium - Zirconium - Niobium. The composition U-5 wt. % Zr-1.5 wt. % Nb has been shown to be resistant to aqueous corrosion when quenched from the gamma phase[7]. Because of interest in this alloy with regard to its possible use in boiling water reactors, extensive studies have been made of its behaviour when subjected to irradiation.

It was learned that the alloy in the as-swaged condition elongated under irradiation at a rate of $G_1 = 150$, and that when this material was

quenched from the gamma phase for corrosion resistance, G_1 increased still further to a value of about 300. Certain heat treatments, however, were effective in reducing the growth tendency of the material. For example, specimens of the alloy which had been allowed to transform isothermally at 650°C. for 24hr showed growth coefficients as low as 5.4.

The use of a duplex heat treatment has been investigated whereby the alloy was first heat treated for dimensional stability and then quenched from the gamma phase for corrosion resistance. Of the heat treatments studied, it has been found that the final quench for corrosion resistance invariably produces material that elongates rapidly under irradiation, regardless of whether or not the alloy had been given prior heat treatment for dimensional stability. It has appeared that material which was fairly well stabilized still contained sufficient anisotropy to strongly influence the texture of the distorted alpha structure resulting from the subsequent quenching transformation.

Aqueous corrosion tests by Greenberg[5] have shown that at 315°C. the gamma-quenched alloy can retain its corrosion resistance up to burnups of about 0.07 at. %. Beyond this level of exposure, the alloy disintegrates in a manner that suggests that radiation may have altered the structure in a manner similar to that produced by over-ageing.

Gamma Phase Uranium Alloys

1. Uranium-Fissium. In the pyrometallurgical process developed at Argonne for reprocessing fuel elements discharged from fast breeder reactors, studies have indicated that a group of fission product elements cannot be removed and that these impurities will tend to build up to an equilibrium amount after several successive recycles of the fuel[8]. The ratio of these elements among themselves is expected to remain fairly constant, but the level to which they accumulate in the fuel can be controlled by varying the amount of burnup and the efficiency of the process. The residual fission product elements are referred to collectively as " fissium ."

In order to determine the effects of irradiation on various fissium alloys, a series of experiments have been performed by Smith (Argonne), on fissium alloys which simulate the estimated composition of equilibrium alloys resulting from reprocessing. For example, a U-5 Fs (fissium) alloy had the following nominal composition: 95 wt. % U, 2.5 wt. % Mo, 0.2 wt. % Zr, 1.5 wt. % Ru, 0.3 wt. % Rh, and 0.5 wt. % Pd. Other fissium alloys described in following sections contained approximately the same ratios of fissium elements, although in differing total amounts.

It has been shown that fissium additions to uranium markedly alter the transformation kinetics[6]. The alloys are characterized by sluggish transformations, so that if sufficient fissium is present, the gamma phase is retained even with slow cooling. As might be expected, these characteristics strongly influence the irradiation behaviour of the alloys. For example, U-3.17 wt. % Fs, which does not retain gamma on quenching, is most stable when allowed to isothermally transform from gamma. G_1 values for wrought gamma-quenched specimens are reduced from about 50 to —0.1 by holding the alloy at 650°C. for 24 hr.

On the other hand, U-5.0 wt. % Fs alloy, which can retain gamma when quenched, was found to show comparable stability only when quenched from the gamma phase. Studies are in progress to determine if the fissium alloys show irradiation-induced phase reversal tendencies as have been demonstrated for other gamma-phase alloys[9,10].

2. Uranium-Fissium-Molybdenum. The effect of increasing the amount of molybdenum in uranium-fissium alloys was investigated by adding 2.5 and 7.5 wt. % molybdenum to cast U-5.0 wt. % Fs alloy. The effect of the additional molybdenum was to cause the irradiation growth coefficient of the alloys to become essentially independent of prior heat treatment. Thus, the U-5.0 wt. % Fs-2.5 wt. % Mo alloy showed a growth coefficient of approximately 2 regardless of whether the alloy was quenched from the gamma phase or very slowly cooled. Similar behaviour was shown by the U-5.0 wt. % Fs-7.5 wt. % Mo alloy. An additional effect of the increased molybdenum was to improve the surface smoothness of the alloys during irradiation.

3. Uranium-Plutonium-Fissium. Two compositions, U-20 wt. % Pu -5.4 wt. % Fs and U-20 wt. % Pu -10.8 wt. % Fs have been irradiated in the as-cast condition. Both compositions showed excellent dimensional surface stability, with average G_1 values of 1.8.

4. Uranium-Plutonium-Molybdenum. The composition U-20 wt. % Pu-5.0 wt. % Mo was irradiated in the as-cast condition. The growth co-efficient of this material averaged 3.2, and, as was the case in the above uranium-plutonium-fissium alloys, excellent surface smoothness was retained during irradiation.

Natural thorium consists of a single isotope, Th-232, which is not fissionable to any appreciable extent. However, as is well known, it can capture neutrons to produce protactinium which by a process of beta decay is converted into fissile U-233. Thus, fissions cannot be produced to any significant extent in thorium metal until extended exposure has produced adequate amounts of U-233. In order to obtain information in a reasonable time on the behaviour of fuels based on thorium, irradiations have been made on thorium and thorium oxide to which has been added U-235.

A. Thorium and Thorium-Uranium Alloys. Thorium is a cubic metal and one might surmise, therefore, that it would not develop under irradiation the marked anisotropic dimensional changes which characterize orthorhombic uranium. This expectation has been confirmed by irradiation experiments on unalloyed thorium and on thorium containing additions of 0.1, 1, and 5 wt. % U-235. Specimens of thorium and the above alloys were irradiated to burnups ranging up to 4.4% of all atoms at temperatures ranging from 50 to 200°C. It was found that dimensional changes were small and appeared to have resulted principally from isotropic volume increases in the fuel. The average rate of volume increase was only about 1 % per at. % burnup, or about one-fourth the rate of volume increase shown by unalloyed uranium. G_1 values ranged from 0.065 to 0.85. Composition of the specimens within the range investigated did not appear to have influenced their dimensional stabilities. Thorium and thorium-uranium

alloys irradiated at higher temperatures have also shown excellent stability[11].

B. Tho_2-UO_2 Fuels. The use of oxide fuels in nuclear reactors offers certain advantages, among which are aqueous corrosion resistance, dimensional stability under irradiation,-and high melting point. To a large extent, however, the poor thermal conductivities of oxide fuels offset the advantage of high melting point.

Although most studies on oxide fuels have been confined to UO_2, it is of interest that solid solutions of ThO_2 and UO_2 have certain favourable characteristics which UO_2 does not. For example, Tho_2-UO_2 bodies can be sintered in air,[12] whereas UO_2 must be sintered in a reducing or protective atmosphere. Also, the use of thorium atoms in the fuel enables thermal breeding of U-233.

Compositions that have been subjected to irradiation tests include ThO_2 with 2.5 wt. % UO_2, 6.36 wt. % UO_2 and 10 wt. % UO_2. The specimens were in the form of pellets, approximately $\frac{1}{4}$ in. in diameter by about $\frac{5}{8}$ in. long, and were made by pressing mixtures of ThO_2 and U_3O_8 at 10,000 lb/sq.in. and firing in air at 1,800°C. The compound U_3O_8 reverts to UO_2 during firing[12]. Densities of the specimens ranged from 85 to 90% of theoretical.

Some of the ThO_2-2.5 wt. % UO_2 specimens were irradiated with no cladding, whereas others were jacketed in Zircaloy-2 or stainless steel. Materials used in the annuli between the clad pellets and their jackets included air or NaK. The specimens were highly stable under irradiation and showed dimensional changes of less than 0.0002 in. Metal atom burnups ranged up to 0.75%, and central fuel temperatures during irradiation were calculated to have ranged up to 1,500°C.

Pellets of the ThO_2-6.36 wt. % UO_2 composition were irradiated in Al-1 wt. % Ni alloy tubes, with lead in the annulus between the ceramic pellets and the aluminium alloy tube. The tube was cooled with water at 45°C. Specimens of this type have been irradiated with no difficulty to burnups of several per cent. of the metal atoms and with surface heat fluxes on the order of 500,000 B.t.u./hr-ft.

The Tho_2-10 wt. % UO^2_2 specimens were irradiated in jackets of Al-1 wt. % Ni alloy, and the annulus between the pellets and cladding was filled either with lead or a gas mixture of 20% argon and 80% helium. The dimensional stability of these specimens equalled that shown by the ThO_2-2.5 wt. % UO_2 material. Some of the specimens were irradiated under conditions where the aluminium jackets or even the interior of the specimens themselves melted. These specimens, of course, showed damage in the form of fragmentation.

Two specimens were irradiated at lower temperatures to illustrate an improvement in over-all performance provided by a lead bond. Both specimens were irradiated under identical conditions, but whereas the lead-bonded assembly showed no damage, the gas-bonded assembly showed a break in the cladding. It was learned that the pellets in both specimens had fractured into several smaller pieces.

In the metal bonded assembly, the lead, which was solid throughout irradiation, kept the fuel fragments fixed in their original geometry. On the other hand, the fuel fragments in the gas-bonded assembly had shifted about somewhat during irradiation. One of these fragments, which was projecting outward, was found just beneath the break in the cladding and presumably caused the failure in the jacket.

Conclusion

It has been shown that although unalloyed uranium with suitable metallurgical treatment can be subjected to burnups on the order of 2 at. %, damage is severe. The deleterious changes which occur at moderate irradiation temperatures are principally because of surface roughening and anisotropic growth. Certain alloying additions greatly refine the grain size in uranium, thus eliminating surface roughening. Furthermore, alloying additions can alter the transformation kinetics of uranium so that preferred orientations resulting from fabrication procedures may be largely removed by heat treatment.

For alpha-phase alloys, these heat treatments usually consist of holding the material briefly in the gamma phase, followed by an extended isothermal anneal to permit the alloy to transform completely to alpha. For alloys which can retain the gamma phase on cooling, the preferred heat treatment is usually a quench from the gamma phase, which may be preceded by a homogenizing anneal at gamma temperatures. Both uranium and uranium-base alloys show definite irradiation temperature limitations, above which swelling occurs. Thorium and thorium-uranium alloys show dimensional stabilities which are superior to those shown by the metallic uranium fuels. Oxide fuels are characterized by even better stability under irradiation. Pellets of ThO_2 with additions of UO_2 show negligible dimensional changes after burnups on the order of 1% of the metal atoms with central temperatures of 2,000°C. or more during irradiation.

(Concluded)

References

[4]WHITE, D. W., Jr., "Transformation Kinetics in Uranium-Chromium Alloys." *J. Metals*, 7:11, 1221 (1955).

[5]GREENBERG, S., and DRALEY, J. E., "Effects of Irradiation on Corrosion Resistance of Some High Uranium Alloys." *Nuc. Science and Eng.*, 3:19-28 (1958).

[6]CHISWIK, H., H., LLOYD, L. T. DWIGHT, A. E., NEVITT, M. V., and ZEGLER, S. T., "Advances in Uranium and Uranium Alloys." Proceedings, Second International Conference on the Peaceful Uses of Atomic Energy (1958).

[7]DRALEY, J. E., GREENBERG, S., and RUTHER, W. E., "The High Temperature Aqueous Corrosion of Uranium Alloys Containing Minor Amounts of Niobium and Zirconium." ANL-5530 (1957).

[8]BURRIS, L., *et al.*, "Developments in Melt Refining of Reactor Fuels." Proceedings, Second International Conference on the Peaceful Uses of Atomic Energy (1958).

[9]BLEIBERG, M. L., JONES, L. J., and LUSTMAN, B., "Phase Changes in Pile-Irradiated Uranium-Base Alloys." *J. Appl. Physics*, 27:1270-83 (1956).

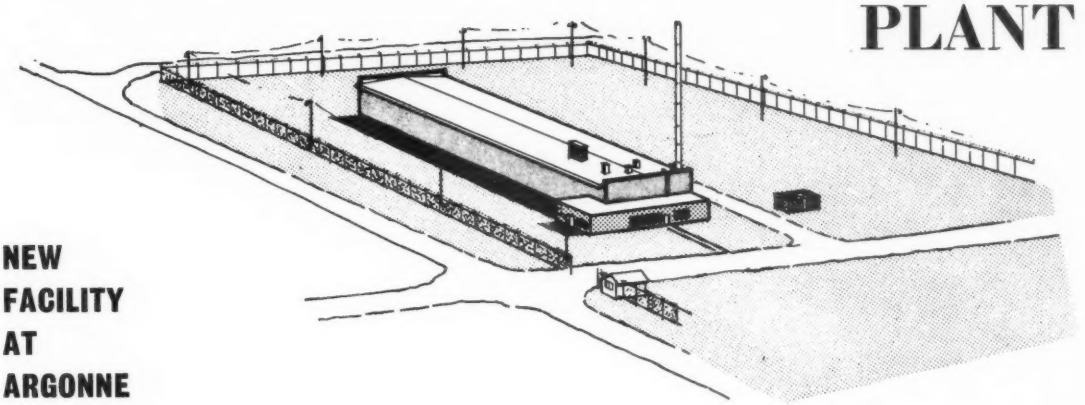
[10]KONOBEEVSKY, S. T., PRAVDYUK, N. F., and KUTAITSEV, V. I., "Effect of Irradiation on Structure and Properties of Fissionable Materials." Proceedings, International Conference on the Peaceful Uses of Atomic Energy, 7:433-440 (1955).

[11]HAYWARD, B. R., and BENTLE, C. G., "Effects of Burnup on Metallic Fuel Elements Operating at Elevated Temperatures." Proceedings, Second International Conference on the Peaceful Uses of Atomic Energy (1958).

[12]HANDWERK, J. H., ABERNETHY, L. L., and BACH, R. A., "Thoria and Urania Bodies." *Bull. Am. Ceram. Soc.*, 36:99-101 (1957).

Acknowledgement is made by the Editor to Argonne National Laboratory for supplying photographs used in this article.

PLUTONIUM FUEL FABRICATION PLANT



NEW FACILITY AT ARGONNE

A BUILDING devoted exclusively to the production of plutonium fuel elements was recently put into operation at the US Atomic Energy Commission's Argonne National Laboratory, at Lemont, Illinois. Known as the Argonne Fuel Fabrication Facility, it will be used for the fabrication of fuel elements for several of the laboratory's nuclear reactors and for the production of test pieces for metallurgical, physical and chemical research.

Completion of the facility is part of Argonne's long term metallurgy programme, This includes a Fuels Technology Centre, now under construction and due for completion by 1960, and the building of plant for the reprocessing of irradiated fuel used in Experimental Breeder Reactor II. The Fuels Technology Centre, which will cost $17m., will be used for carrying out research at present undertaken in the Argonne chemistry building, but on a much larger scale. Many of the research efforts carried out there will receive practical application in the Fuel Fabrication Facility.

Three years were spent by Argonne scientists in designing the facility and two years went into its construction. $4m. were spent in building and equipping it.

At the same time as it meets specific requirements for the processing of nuclear fuel, the facility is designed to afford operating staff the maximum safety from health hazards. Provision is also made for the complete protection of the surrounding area against the spread of radioactivity.

Sealed Off Portions

The facility occupies a building 245 ft long and 72 ft wide. Portions of the building where radioactivity may be present are completely sealed to the outside. Main exterior walls are of monolithic reinforced concrete sealed on the outside with a polyester plastic coating and painted on the inside with vinyl paint. All floors in areas where there is risk of radioactive contamination are covered with built up fibreglass and polyester coating. Basement floors and floors bearing on the ground are sealed in the same manner.

There are three working zones in the building, divided according to use and possible radiation hazard. These are an administration area, a technical area, and a fabrication area. Each is completely sealed from the other areas with access between areas by means of an air lock.

The administration area consists of a lobby, offices, a counting room, and clothing change rooms. This area is considered to have no more likelihood of contamination than any office or street in the immediate vicinity of a closely controlled radioactive materials laboratory. The area is air conditioned and ventilated in the same manner as any uncontaminated office.

The technical area contains storage vaults for radioactive materials, a mechanical laboratory used for the

Initial Pu Fuel Reactor Tests

Plutonium fuel elements will be made for:—
Experimental Breeder Reactors I and II (EBR-I, EBR-II)
Experimental Boiling Water Reactor (EBWR)
Zero Power Reactor III (ZPR-III)

EBR-I is an unmoderated fast reactor cooled by a sodium potassium alloy. It has a heat output of 1,400 kW and electrical capacity of 400 kW.

As originally designed and fuelled with U-235, breeding ratio of EBR-I was 1.0.

With modifications to the fuel this was increased to 1.2.

With plutonium it is hoped to further increase this to 1.5.

EBR-II, which is now under construction and expected to go critical in 1960, will have a heat output of 62,500 kW and electricity capacity of 20,000 kW.

Its first fuel loading will be of uranium.

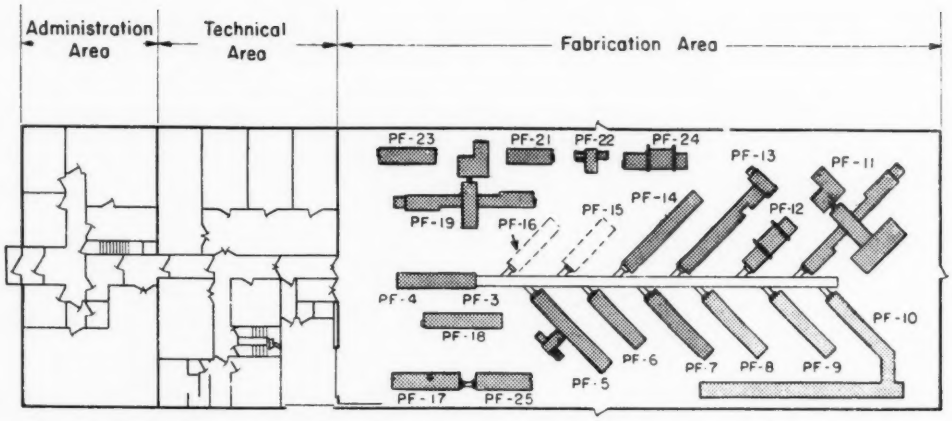
Its second fuel loading will contain 20-30 per cent. U-235, 20 per cent. Pu-239, 10 per cent. of a fission product mixture, and the remainder U-238.

EBWR has a heat output of 20,000 kW and electricity capacity of 5,000 kW. Modifications being carried out will raise the heat output to 100,000 kW.

Modifications call for a new core design with U-235 as the fissionable material. Later however, fuel studded with plutonium will be used.

One of three types of element will probably be used—an aluminium-plutonium alloy, aluminium-plutonium cermet, or a zirconium-plutonium ceramic.

ZPR-III will be used for the testing of plutonium fuel elements encased in stainless steel jackets. Experiments will help determine the proper amounts of this metal to be used in various fast reactor systems.



Plan of the facility showing layout of the various processing sections in the fabrication area. Key to these sections: PF-3—Conveyor; PF-4—Introduction and removal; PF-5—Machine shop; PF-6—Electrolysis and aqueous solution; PF-7—Weighing and inspection; PF-8—Centrifugal casting; PF-9—Ingot casting; PF-10—Extrusion press; PF-11—Rolling mill " A "; PF-12—Plate shear; PF-13—Wire fabrication; PF-14—Press work; PF-15—Future line; PF-16—Future line; PF-17—Welding and cladding; PF-18—Decontamination; PF-19—Rolling mill " B "; PF-21—Work bench; PF-22—Milling machine; PF-23—Lathe; PF-24—Plate shear; PF-25—Liquid metal filling

maintenance or modification of equipment and for tooling, X-ray rooms, dark rooms, a health physics work room, and a storage room. Contamination here would result only in case of a handling accident or of tracking contaminated material from the fabrication area. Three air locks with electrically interlocked doors isolate the technical area from other parts of the building.

Processing in One Room

The fabrication area is used for all work performed directly on radioactive materials or on reactor fuel pieces containing radioactive materials. While every effort is made to keep all space where personnel work free of contamination, the contamination risk is greatest in the fabrication area. All process equipment is assembled in the single 165 ft × 72 ft fabrication room.

Reinforced concrete floors and roof decks are employed throughout the building except for the roof above the fabrication area. Here it was necessary to use a precast gypsum slab roof supported by 74 ft steel trusses. A fire retardant vermiculite plaster ceiling was placed below the trusses. Walls separating the three major working zones, and interior walls in the basement of the building, are of reinforced concrete. Other walls are of concrete block masonry.

Air is supplied to each of the three main operating areas by means of a separate air conditioning system. Replaceable filters are employed on the air supply to the technical and fabrication areas. The air supply is humidity controlled.

The exhaust ventilation of the fabrication area includes three types of systems.

1. A once-through system for exhausting air from the process enclosures where work is done on reactor fuel pieces.

2. An emergency stand-by or purge system which operates constantly and which, in event of failure of the normal ventilation, is automatically opened to provide ventilation of the process enclosure.

3. A once through filtered air system to exhaust the room air and to ventilate auxiliary equipment housed in secondary enclosures below the primary process enclosures.

The philosophy of preventing airborne radioactive dust from spreading between areas of the building is to keep air moving inward so that there is no leakage from the technical area to the administration area or from the fabrication room to the technical area even when air locks are opened. This is accomplished by keeping the technical area at a lower pressure (0.05 in. water gauge lower) than the outer atmosphere, and the fabrication room, where radioactive dust is most likely to originate, at a still lower pressure (0.125 in. water gauge lower than atmospheric pressure).

View of fabrication area looking towards the entrance. At far right can be seen end of conveyor line

The technical area is established as a reference zone against which fabrication area and administration area pressures are set by means of exhaust fans and dampers. The administration area is kept at approximately atmospheric pressure.

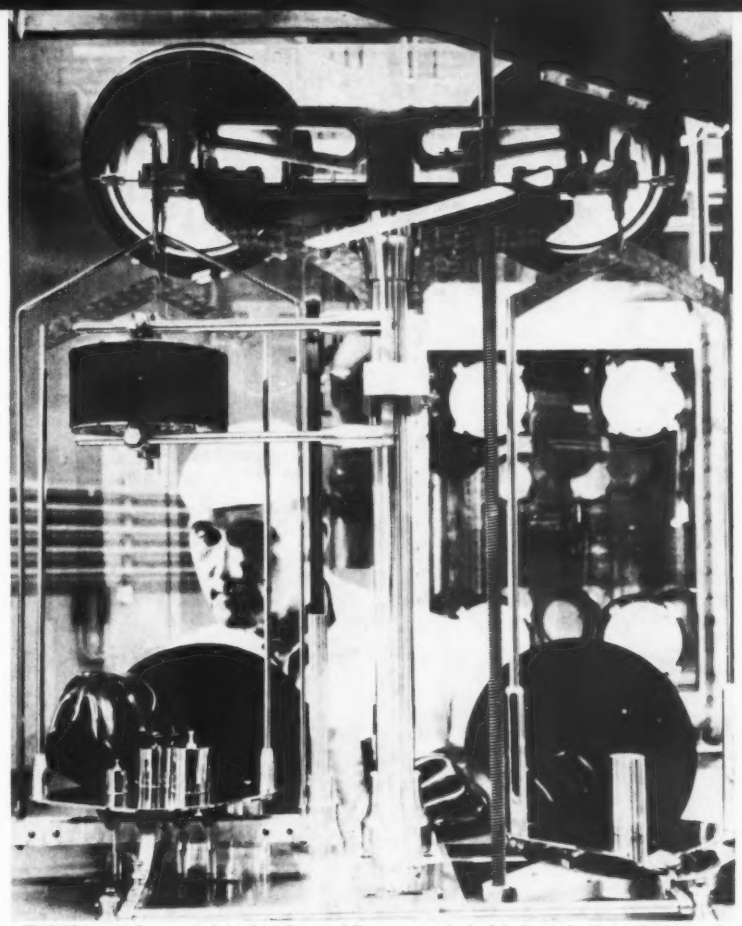
All of the air exhausted from the building is filtered through AEC high efficiency fire-resistant filters. These filters are tested to be effective against 99.95 per cent. of all $^{1}/_{10}$ micron size particles before installation. Double filter banks in series are used to remove contamination from the air exhausted from all highly contaminated areas such as the inside of the hoods. Single filter banks are employed for room air exhaust. In addition to double filtration, all of the air exhausted from contaminated zones is piped through a 100 ft high stack at the south side of the building. This allows dissipation of any gaseous radioactive process products that may remain to a value well below maximum permissible limits.

Looking down conveyor line from east end. On the immediate left and right of entrance are photoelectric light cells

Four Types of Work

Work carried out in the fabrication area is of four types:

1. Fabrication of reactor fuel elements containing plutonium alloys;
2. Assembly, welding, and bonding of previously fabricated plutonium cores in non-radioactive jacket materials;
3. Metal working, machining, cutting and heat treating of jacketed pieces; and
4. Inspection or other operations upon finished elements.



Weighing specimen of plutonium in one kilogram analytical balance in the weighing and inspection section (PF-7)

To protect operating staff against alpha particle contamination the equipment is enclosed in glove boxes. These are gasketed together to prevent air leakages and they can be used either with air or helium gas, depending upon the material and operation. There are 106 glove boxes, ranging from 18 to 800 cu.ft in volume.

To facilitate flexible operation the whole plant is laid out in sections, where different kinds of work can be carried out, rather than in one long continuous production line. Each section is made up of a group of equipment and machinery served by a central 102 ft long hooded conveyor. This comprises two rails upon which a dolly is drawn by a continuous roller chain. The sections are laid out at an angle of 135° to the axis of the conveyor and transition of material from the conveyor to a section is made by means of a two-way ball-bearing slide platform.

The sections are separated from the conveyor by means of gas-tight pneumatically-operated sealing doors.

The first section (PF-5) contains a 50-ton hydraulic press, 10 in. toolmaker's lathe, vertical milling and drilling boring machine, sheet metal shear, universal tool grinder and milling machine. The second section (PF-6), called the aqueous solution line, contains a 4 kW rectifier and appropriate controls.

PF-7, as the next department is coded, is a weighing and inspection line. It contains two 200 grammatic balances, 1 kg capacity analytic balance (with a 0.2 mg sensitivity); 5 kg capacity balance (0.5 mg sensitivity) with keyboard fractional weight and chain milligram weights; and a Rockwell hardness tester. Space is left for special gauging and non-destructive testing equipment.

Casting Section

The centrifugal casting line (PF-8) contains two vertical spindle, rotary table, vacuum centrifugal casting machines capable of melting 10 kg of plutonium alloy at a vacuum of 0.0001 mm of mercury and casting the alloy under centrifugal forces of up to 80G. The ingot casting

line contains a bell jar type vacuum chamber furnace fitted with induction equipment capable of melting up to 10 kg of alloy under a vacuum of 0.0001 mm mercury and gas pressure injection casting machine for the production of small diameter rods.

Equipment for the extrusion press department (PF-10) is still to be delivered. It consists of a 600 ton extrusion press.

The rolling mill line (PF-11) contains a two-high, four high rolling mill with 10 in. diameter by 14 in. two-high work rolls and four high backing rolls and 2½ in. diameter by 14 in. four high work rolls. There is also a vacuum rod-annealing furnace designed to anneal billets at temperatures of up to 1,200°C. in a 0.0001 mm mercury vacuum.

Plates are cut in PF-12, which contains a specially designed ½ in. × 6 ft capacity plate shear. The next department (PF-13) provides for the fabrication of small wire and foil specimens and is equipped with a ⅛ in. capacity swaging machine, high vacuum annealing furnace, hydraulic draw bench, ⅝ in. capacity rotary swaging machine and a two-high four high rolling mill with 5 in. diameter.

PF-14 is the pressing and powder working line equipped with a 250 ton down acting, four column press and semi-portable vacuum pressure furnace and a high temperature bell jar sintering furnace.

Welding is carried out in PF-17 and liquid metal bonding in PF-25. Blast cleaning machine, electrolysis equipment and vapour degreaser are provided in PF-18 for decontamination of materials and specimens. Ultrasonic cleaning apparatus is planned for later installation.

Much of the processing equipment is duplicated in further departments and provision is made for additional glove boxes to be brought into service if necessary.

The helium gas system which serves the glove boxes is designed to handle gas at a rate of either 1,000 or 2,000 cu.ft/min. As helium is an expensive and scarce product care is taken in its use and the system is provided with a regenerative purifying circuit capable of handling about 100 cu.ft. of gas/min. About 10,000 cu.ft of gas is kept circulating by this means.

Book Reviews

Physics and Heat Technology of Reactors (Translated from the Russian—Supplement No. 1 of the Soviet Journal of Atomic Energy "Atomnaia Energia.") Published by Chapman and Hall. Size 8½ in. × 11 in. × 174 pp, profusely illustrated. Price £8 8s.

Mathematical physicists and especially those learned in nuclear science will welcome this book. It is frankly a revealing picture of the immense progress Soviet physicists have made in recent years and, among other things, it provides the reader with excellent references to literature, especially Soviet literature, on this rapidly growing specialized region of physical science. Right away, it must be admitted that this really important publication, which has apparently been faithfully translated, might as well be in Russian for any sense the non-mathematical reader could make from it. In fact, this remarkable collection of original Soviet research will be intelligible to the reader who understands the following displayed equations as he believes that 2+2=4, viz., where γ_i is the efficiency of the fissionable material under review, then

$$\gamma_i = \lim_{\Delta\rho f \to 0} \frac{\frac{\Delta k_{eff}}{k_{eff}+\Delta k_{eff}}}{\frac{\Delta\rho f}{\rho f}} = \frac{\rho f}{k_{eff}}\left(\frac{\partial k_{eff}}{\partial \rho f}\right)_V =$$

$$= \frac{1}{\int_V dV \int_{\infty}^{\infty} \frac{\nu_{eff}^{(u)}}{k_{eff}} \Phi \Sigma_{af}^{f} du \int_{-\infty}^{\infty} \chi \Phi^{+} du} \int_V dV \int_{-\infty}^{\infty} \times \left\{ \Phi \Sigma_{alf} \left[\frac{\nu_{eff}}{k_{eff}} \frac{\Sigma_{af}^{f}}{\Sigma_{alf}^{f}} \int_{-\infty}^{\infty} \chi \Phi^{+} du + \right.\right.$$

$$\left.\left. + \frac{\Sigma_{ln}^{f}}{\Sigma_{alf}^{f}} \int_{u}^{\infty} S^{f}(u \to u') \Phi^{+} du' - \Phi^{+}(u,r) \right] + \frac{\Sigma_{tr}^{f}}{3\Sigma_{tr}^{2}} \nabla\Phi\nabla\Phi^{+} \right\} du.$$

From this it is clear that this publication is essentially one for the advanced student, but even the enthusiastic reader who is not too hot on mathematics will get some enlightenment from these pages. Nuclear science, as this publication shows, is a meeting ground for mathematicians, physicists and engineers. Eventually it will settle down so that the engineer can make use of his technique without abstruse mathematics, but engineers will have to realise that in the future they will have to be familiar with something more than such simple equations as $PV=RT$. To the engineer who has had the benefit of an advanced training in mathematical physics, there is much of value in this work especially heat problems connected with power reactors and how to obtain the highest utilization of the heat generated in the core of the reactor. It includes some material of which little or nothing has so far appeared in any literature and it, therefore, qualifies for a place in the library of the nuclear technician.

D. S. WATT

Peaceful Uses of Atomic Energy—Proceedings of the Second United Nations International Conference, Geneva, 1958. English Version: Volumes 1-33. Published by United Nations.

The editors responsible for putting the papers presented at Geneva are to be congratulated on doing a magnificent job of work. Over 2,100 papers were submitted by 46 nations and six intergovernmental organizations. Five technical concurrent sessions were held every morning and most afternoons during the conference at which papers were presented orally, each session covering a specific aspect of nuclear energy. The papers are published in the order they were presented at these sessions. Also included in the proceedings is a record of the discussions that followed each session. The titles of the 33 volumes are as follows:—1 Progress in Atomic Energy; 2 Survey of Raw Material Resources; 3 Processing of Raw Materials; 4 Production of Nuclear Materials and Isotopes; 5 Properties of Reactor Materials; 6 Basic Metallurgy and Fabrication of Fuels; 7 Reactor Technology; 8 Nuclear Power Plants—Part I; 9 Nuclear Power Plants—Part II; 10 Research Reactors; 11 Reactor Safety and Control; 12 Reactor Physics; 13 Reactor Physics and Economics; 14 Nuclear Physics and Instrumentation; 15 Physics in Nuclear Energy; 16 Nuclear Data and Reactor Theory; 17 Processing Irradiated Fuels and Radioactive Materials; 18 Waste Treatment and Environmental Aspects of Atomic Energy; 19 The Use of Isotopes: Industrial Use; 20 Isotopes in Research; 21 Health and Safety: Dosimetry and Standards; 22 Biological Effects of Radiation; 23 Experience in Radiological Protection; 24 Isotopes in Biochemistry and Physiology—Part I; 25 Isotopes in Biochemistry and Physiology—Part II; 26 Isotopes in Medicine; 27 Isotopes in Agriculture; 28 Basic Chemistry and Nuclear Energy; 29 Chemical Effects of Radiation; 30 Fundamental Physics; 31 Theoretical and Experimental Aspects of Controlled Nuclear Fission; 32 Controlled Fusion Devices; and 33 Index of Proceedings.

NUCLEAR ENERGY DEVELOPMENTS IN

ASIA

Japan is so far the only Asian country outside the U.S.S.R. in which installation of a nuclear power station looks like becoming a reality. It will be a 150 MW British designed type of station due to be in operation by mid-1963. India has plans for a nuclear power station, also of British design, to be operating by 1964, but no definite arrangements have yet been made. In other countries of the continent nuclear energy goes no further than research and the use of radio-isotopes, mainly for economic reasons.

by J. BURKETT

INDIA

INDIA is an example of a low income country in the course of rapid industrialization. Enormous effort is being made in India to raise the living standards of the 400m. people. It is already one of the two largest producers of textiles in the world and its manufactures include steel, locomotives, trucks, machine tools, heavy chemicals and fertilizers.

As the standard of progress in a country is measured by its *per capita* production, the latter would have to be raised to very large proportions to attain a substantial increase in these living standards. For instance, to equate with electric power production *per capita* in the U.S.A., India would have to have an installed capacity of roughly 250×10^3 MW. In 1956 electric capacity was 3.5×10^3 MW whilst the target for 1961 is 7×10^3 MW. Of this, 3×10^3 MW will be from hydro-electric plant, 3.55×10^3 MW from coal-burning stations whilst the remainder will be made up by diesel plants. Even so, the total installed capacity will be short of the estimated demand by 3×10^3 MW.

Hydro Power Too Dear

Total hydro power potential is estimated at 35,000-40,000 MW but some of this is in difficult locations and the last 5-10m. MW might be too expensive to develop. Even if the whole were fully harnessed it would represent only one-tenth kW of installed capacity *per capita* compared with about 0.63 kW in U.S.A. and 1.1 kW in Norway. Total coal reserves estimated at 40,000m. tons or more represent one-twentieth of the *per capita* coal reserves of China, a thirty-fifth of those of the United Kingdom and $^1/_{125}$th of American reserves. Known reserves of coal and hydro-electric power, therefore, are not sufficient to sustain for more than about 20 years a living standard comparable to that in the technologically advanced countries.

There are regions in India where there is either no hydro or coal or where hydro power is fully developed such as in Madras State. Ahmedabad in Bombay State, a major textiles city, is over 800 miles from the coal fields of Bengal and Bihar where over 80 per cent. of India's coal is mined. If the rapid rate of industrialization planned up to 1986 is to continue, the distribution of coal fields, limited rail transport capacity and great shortage of power in certain areas are all factors that make it possible for the installation of nuclear power capacity.

A tentative programme estimates a capacity of 1,000 MW by 1966, based on first stage natural uranium reactors costing about £130/kW and competitive in high coal-cost areas. The likely capital cost for future hydro schemes is thought to be also in the region of £130/kW. It is understood that authority has now been given for construction to start on a 250 MW(e) nuclear power station at Ahmedabad, with completion by 1964. A Calder type will be supplied from this country on the basis of deferred payment. Apparently U.S. designed packaged reactors have also been considered but it is thought that these have been rejected on the grounds that enriched fuel purchases would draw too much on dollar resources.

Thorium Future

Installed capacity by 1967 from second generation fast or thermal breeder reactors is estimated at 250-330 MW whilst in the third stage, U-235-thorium breeders will provide 230 MW per annum from 1969, arriving at a total output of 1,600 MW by 1974, over 5,000 MW by 1979 and well in excess of 12,000 MW by 1984. This long-term programme has been related to the availability of the necessary raw materials. The known reserves of uranium in ore containing more than 0.1 per cent. amount to over 30,000 tons whilst the total reserves of thorium are estimated at about 500,000 tons. Uranium reserves by themselves, assuming an average rating of 4 MW (heat)/ton, would be inadequate for long-term power needs.

Plans have been put into action for the production of heavy water and a plant is being constructed under the supervision of the Vitro Engineering Division on the banks of the River Sutlej in the Punjab. Annual production is expected to be 14 tons in addition to 70,000 tons of nitro-limestone for fertilizer. Dr. J. H. Bhabha, chairman of the Atomic Energy Commission, considers that the plant will eventually produce heavy water at lower than U.S. prices.

Nuclear research is being carried out at the Atomic Energy Establishment at Trombay. The 1 MW pool reactor APSARA, which has been operating since August, 1956, was not only designed by Indian engineers and scientists but also fabricated by them, apart from the enriched fuel elements supplied by the UKAEA. In addition to its use in training personnel and making nuclear studies, small quantities of isotopes are produced and different types of grains and seeds are irradiated.

Under the Colombo Plan, a high flux research reactor of the NRX type for materials testing and engineering loop experiments is being designed and constructed by Canada with India assuming responsibility for carrying out certain civil works and all necessary auxiliary services and facilities. India is supplying fuel elements fabricated at Trombay from locally produced uranium, whilst the heavy water is coming from the U.S. Atomic Energy Commission. When this 40 MW (heat) reactor commences operation by the end of 1960, it will be available to scientists from other countries in South and South-East Asia.

Further details can be obtained from the following papers presented at the 2nd International Conference on the Peaceful Uses of Atomic Energy:—P/1624—Contribution of atomic energy to a power programme in India; P/1625—The first Indian reactor—Apsara; P/1642—Study of fuel cycles with reference to a power programme; P/1649—Production of heavy water in India; P/1704—The Canadian-India reactor at Trombay; P/2424—The Canadian-India reactor: an exercise in international co-operation; and P/1641—Natural uranium reactor for small and medium power outputs.

PAKISTAN

SINCE the partition, Pakistan has been making strenuous efforts to raise the living standards of its people and to develop the country's economic potential. In the past 11 years industrial production has grown by 380 per cent., resulting in a rapidly increased demand for power.

Apart from the difficulties raised by East and West Pakistan being separated by 1,000

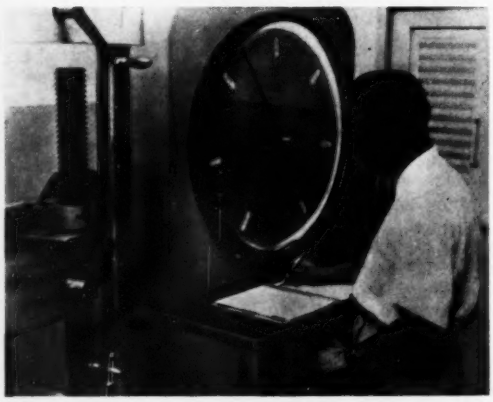
miles of alien territory, partition left India with nearly all known sources of high-grade coal and Pakistan with only low-grade coal and lignite. Of the 2m. tons of coal required each year, only 500,000 tons is produced in West Pakistan, the remainder being exported mainly from India with a small proportion coming from South Africa and China. A small oil field in the Punjab provides only 20 per cent. of the oil requirements. The total reserves of natural gas, however, estimated at 215×10^6 tons (coal equivalent), are adequate for boiler fuel purposes in those areas within reach of the gas fields at Sylhet and Sui.

The total hydro potential in East and West Pakistan is estimated at about 10.4×10^6 kW but its usefulness is limited because this potential exists only at the extreme ends of the country. In the West, the rivers pass through occupied Kashmir, making it impossible to assure continuous supply, whilst in the East floods cause disruption and delays.

The gap between supply and demand of power is growing, leaving the government with the problem of either increasing imports of coal and oil or prejudicing the growth of industrialization. The country relies for much of its foreign exchange earnings on industries based on such raw materials as jute and cotton, on fertilizer manufacture and on the development of mineral resources.

Capital for investment is so short that almost one-third of that required for the first five-year plan will have to come from foreign grants and loans. Urgent development projects therefore compete for the limited resources and it is thought unlikely that investment in large-scale nuclear power will displace development in the gas fields and of hydro installations.

(*Below, top*) **Scientist working at Chulalongkorn University, Bangkok, Thailand, with a reactor material test apparatus** (*Below, bottom*) **Scientists at the university discussing the swimming pool reactor to be supplied by an American company**



In East Pakistan, thermal plants either planned or under construction, are expected to cater for power demands up to 1965. After this period nuclear power plants may be necessary.

In the West, the larger generating plants near the gas pipelines will probably continue to be gas-fired but in remote areas such as the southern regions of Sind, Baluchistan and Karachi, dependent for power on diesel engines, a good case can be made for small nuclear plants. It is possible that these will be competitive before 1975.

Nuclear power research and development is the responsibility of the Atomic Energy Commission, which was established in 1955 in Karachi. Pakistan has an agreement with the U.S.A. for the provision of nuclear fuel and the purchase of a research reactor.

Further details can be obtained from the following paper presented at the 2nd International Conference on the Peaceful Uses of Atomic Energy:—P/1407—The future of nuclear power in Pakistan.

India's Neighbours

CEYLON has considerable hydro-electric power potential capable of development and with the limited financial resources and present lack of trained personnel there is little likelihood of nuclear power being used for a number of years. Burma also has great hydro potential and the only future possibility for nuclear power will be in the Rangoon area where hydro power is not well located.

Viet Nam has recently established a nuclear radiation laboratory and by 1960-61 it plans to have a small U.S. research reactor in operation. Thailand aims to buy an American swimming pool reactor for Chulalongkorn University in Bangkok, with the U.S.A. contributing half the cost. Research facilities will be made available to scientists from Cambodia and Laos.

Further details can be obtained from the following papers presented at the 2nd International Conference on the Peaceful Uses of Atomic Energy:—P/2264—Burma's atomic energy programme; and P/2265—Burma's electric power needs and resources.

CHINA

IN spite of a rapid increase in industrial development, vast coal reserves and hydro potential make it unlikely that nuclear power will be of interest for a long time. A research programme is being pursued, however, at the Atomic Energy Institute in Peking and a Soviet 10 MW heavy water reactor has been working since June, 1958. The radioisotopes produced will have a particular application to agriculture. The Institute also has a Soviet 25 MeV accelerator.

Formosa on the other hand will have exhausted its coal reserves and useful hydro potential by 1968 and the only alternative to fuel imports will be nuclear power. The Taiwan Power Co. has stated that a 150-200 MW nuclear power unit might be built by 1968, and during 1959 it is expected that experts from the International Atomic Energy Agency will assist the government in the establishment of this plant. As a start an International General Electric 1 MW pool-type research reactor is to be installed in the National Tsing Hua University. A grant of $350,000 has been offered by Washington towards its cost.

It is understood that South Korea is setting up a research centre to be administered by an Atomic Energy Commission. The first research reactor may be in operation in 1959 whilst a nuclear power plant is envisaged by 1966. The Ministry of Education has decided to purchase a 100 kW pool-type research reactor from the General Dynamics Corporation and out of the cost of $731,000, a $350,000 grant has been offered by the U.S.A. government.

Further details can be obtained from the following paper presented at the 2nd International Conference on the Peaceful Uses of Atomic Energy:—P/132—Future prospects of nuclear power in the electric power economy of Taiwan.

JAPAN

THE rapid industrial expansion that is being experienced in Japan is likely to continue for at least 20 years. Fossil fuels have to be imported to supplement limited indigenous resources. In 1956, 108.6m. tons coal equivalent was used, of out which 23 per cent. came from foreign sources. The forecasted requirement for 1975 is 271m. tons, 48 per cent. of which will have to be imported.

The need for maintaining balance of payments demands a reduction in imported energy sources, consequently nuclear power development is being regarded as a means of saving a large amount of foreign currency in the long run.

The future cost of conventional power generation is not expected to decrease and, as far as Japan's first-stage exploitation is concerned, it is thought that nuclear power will be able to operate on an economic basis, with the possibility of cost reductions in the future. A Japanese cost estimate for nuclear power generation by a Calder Hall advanced type reactor is given as 4.40-4.75 yen/kWh as compared with 3.85-4.35 yen/kWh for a coal-fired thermal plant and 3.50-4.00 yen/kWh using oil. Whilst a considerable amount of foreign exchange will be required for the initial development stage the reduction of fuel imports is expected eventually to result in large savings.

The estimated generating capacity by 1975 is likely to be 29,300 MW output, out of which 7,000 MW will be provided by nuclear power plant. The first stage in the programme is the provision of 150 MW each year from 1962-65. During this period Japan will have to rely to a large degree on imported equipment whilst it is promoting domestic production and the education and training of personnel. The first commercial reactors are likely to be Calder type because of their adaptability to domestic manufacture and the use of natural uranium. The problem of earthquake damage has been solved apparently (*see pages 349-351*).

The Japanese have selected for their first nuclear power station a Calder Hall type reactor. This will have an electrical output of 150 MW and will be built for the Japan

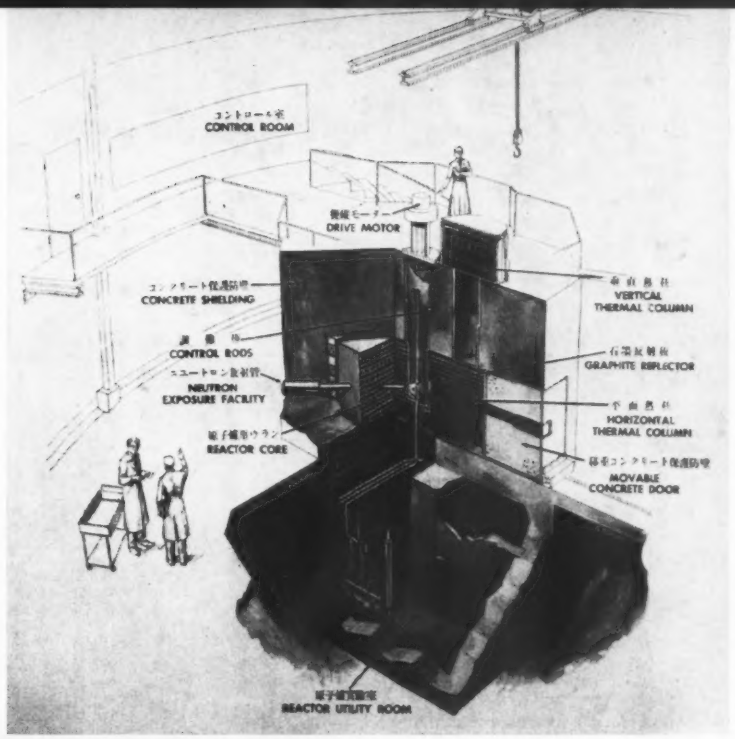
Atomic Power Co. by the GEC/Simon-Carves Group with the UKAEA undertaking to supply the necessary fuel and technical assistance. The station will be at Tokai Mura, 65 miles north-east of Tokyo.

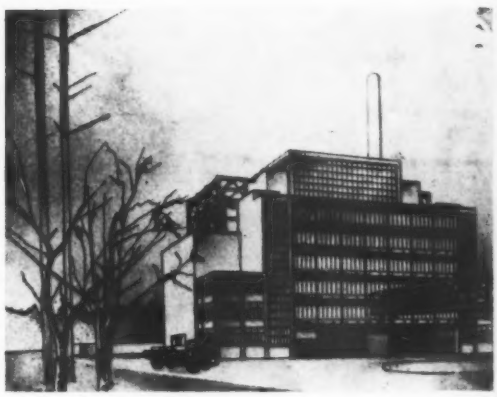
The aim eventually is to save importing reactors, equipment and fuel, consequently it is reckoned that although at first 40 per cent. of Calder type equipment will be imported, by 1967 imports will be down to 7 per cent. A further 300 MW per annum is planned for 1966 and 1967, 600 MW per annum for the period 1968-70, 750 MW per annum for 1971-73 and 900 MW per annum for 1974 and 1975. Installed capacity by then should be 7,050 MW.

Construction of enriched uranium reactors will probably commence in the late 1960s after experience has been gained on an imported 10-15 MW light water research reactor. The programme includes two breeder experiments each of 1-10 MW(e), one a thermal breeder and the other a fast breeder, both to be built by the Japanese. The first commercial-size breeder, 100 MW(e), is planned for operation by 1970.

All the nuclear fuel required for 1961 and 1962 will be imported in the form of fuel elements. From 1963, apart from a small proportion of domestic ores, nuclear fuel will be imported in the form of ore concentrate and then refined and fabricated into fuel elements using Japanese facilities. Foreign fuel requirements will be met through a U.K./Japan bilateral agreement and another with the U.S.A. which provides for the transfer of 2,700 kg of U-235 for use in research, experimental power, demonstration power and full-scale power reactors. The exploitation of nuclear fuels is the responsibility of the Atomic Fuel Corporation.

Further details can be obtained from the following papers presented at the 2nd International Conference on the Peaceful Uses of Atomic Energy:—P/1318—The long-term plan for development of Japanese atomic power reactors; P/1319—Nuclear-powered emigrant ship; P/1320—Nuclear-powered submarine tanker; and P/1336—Design calculation of the Japan-made reactor No. 1 (JRR-3).





(*Above*) Sectional drawing of the 50 kW "solution type" reactor built by Atomics International, a Division of North American Aviation, Inc., for the Japan Atomic Energy Institute. (*Left*) Institute scientists at the controls of the reactor, which went into operation in 1957. (*Below*) Artist's impression of the proposed GEC 150 MW nuclear power station to be built at Tokai Mura, near Tokyo

RESEARCH REACTORS

	Maximum Heat Output	*Fuel*	*Moderator*	*Coolant*	*Thermal Flux*	*Start-up*
JRR-1	50 kW	UO_2SO_4/H_2O (20 per cent. enr.)	—	H_2O	1.3×10^{12}	Aug. 1957
(Design: Atomics International L-54) (Exponential experiment for JRR-3; basic research; production of short-life radioisotopes)						
JRR-2	10 MW	20 per cent. enr.	D_2O	—	10^{14}	1959
(Design: CP5 type, AMF co-operating with Mitsubishi) (Materials testing; basic research; production of isotopes)						
JRR-3	10 MW	Nat. U	D_2O	—	10^{13}	1961
(Design and construction—Japanese)						
JMTR-4	50 MW	90 per cent. enr.	—	—	—	1963
(Materials and Engineering Test Reactor)						
JRR-5	10 MW	—	—	—	—	Planning
Swimming Pool Reactor	—	—	—	—	—	Planning

'NUCLEARIST' writes . . .

CARIBBEAN waters, once the romantic playground of buccaneers, have resounded again with the echoes of strife and unrest. There have been tussles between revolutionaries, invasions by handfuls of men, and petty intrigues, and as in comic opera, men and women have laid down spade and ladle to shout for freedom. Aloof from this turmoil, however, tiny Puerto Rico, under American tutelage, concentrates on the benefits of modern science, and takes pride of place as Central America's atomic pioneer. Atomics International have installed at the Puerto Rico Nuclear Centre in Mayaguez a 10w homogeneous laboratory reactor. This is not to be taken as a sign that within the next few months every house on the island will be lit by nuclear electricity, but from this tiny acorn a mighty oak may grow, especially in a population alive to the possibilities which can materialize when hot-headedness is replaced by reason.

* * *

In another trouble centre yet a further small nation makes its way into the atomic field. Israel is extracting uranium from the Negev phosphate rock. In 1956 the USAEC promised Israel a research reactor. This is to be a swimming-pool type, and will be erected on the coast, near Rishon Lezion. The 3kg of enriched fuel will be obtained on loan from the U.S.A. This reactor will be the property of the Weizsmann Institute and will be used for research and training.

Israeli scientists are anxious to make both progress and contributions in the nuclear field, and at the Plenary Assembly of the World Jewish Congress, to be held in Stockholm in August, the peaceful uses of the atom will appear on the agenda. It is to be hoped that "peaceful" will continue to be an operative word, for incidents on the Israel borders could so easily flare up again, and the booming of guns will not assist peaceful atomic developments.

* * *

Talking of guns, I am reminded that a howitzer of a different kind has been placed on the market by Nuclear-Chicago Corporation. Their Model NH-2 neutron howitzer is an aluminium drum, 35 in. × 23 in., containing 350 lb of paraffin, and designed for the storage of neutron sources and for college demonstrations in nuclear physics. A neutron source can be placed at a given level, and collimated beams obtained through a pair of cadmium-lined ports. The howitzer is suitable for low neutron activation studies, fast and slow neutron shielding experiments, measurement of nuclear radii, and the determination of albedos and reflector characteristics. This device is scheduled as qualifying for grants-in-aid by the USAEC.

* * *

While statesmen were wrangling at Geneva over the problems of nuclear armaments and the control of nuclear weapons tests, the British Prime Minister answered an enquirer in the House of Commons in a very clever way. Asked whether bomb fall-out was serious compared with the increasing use of radiations in medicine and industry, he quoted figures based on the 1956 concept of safety, figures which have since been proved far too optimistic. Perhaps a half-truth is better than an outright lie. For example, take the poster which shouts to us from the hoardings—"Britain leads the world in shipping." We all know that our country has fallen to third place in the world's ship-builders, and that Japan has stolen the march on us. Perhaps this is why another questioner in the Commons was worried about this, but was pacified by the assurance that the Government and the industry are keeping their eyes on the matter.

* * *

Much more encouraging is the British signature to the agreement for the joint development of the high-temperature gas-cooled reactor, which forms the DRAGON project to be worked out at Winfrith Heath. Lord Plowden hit the nail right on the head when he said that this venture was not purely one of collaboration in pioneering, but of pioneering in collaboration. That remark should go down in history with the world's great ones. For heaven's sake let us take more and more part in such collaborative ventures. It is to our credit that although not actively participating in the Eurochemic project for a processing plant at Mol, and the boiling water reactor at Halden, we are at least joining in as advisers. If only we could work together on similar projects with Russia and the other countries of the Communist bloc, this might do more for world peace than all the round-table conferences.

* * *

People have long blamed nuclear tests for the inclemencies of the weather, particularly noticeable in Britain, where we have weather rather than a climate. As if to give them some real grounds for complaint, the Americans now suggest the use of atomic bombs specifically to produce rain. A megaton-equivalent nuclear bomb would throw up into the atmosphere 100 megatons of seawater, not to mention the denizens that lurk in that water. Although gravity is one of the weakest forces in the universe, it is supposed that this water will return as rain, to give an inch over an area of 5,000 sq.km. What is not so certain, of course, is that the rain may be persuaded to come down in the right place. Now just suppose the Americans, in an effort to alleviate the drought in sun-baked Nevada or Colorado, send off a few bombs which produce downpours during a Soviet Wakes-Week on the Black-Sea Coast!

* * *

In the field of documentation, two new ventures have come to my notice. An American foundation is prepared to donate $7,000 to the creation of an international news and correspondence service to be centred at Geneva. This will deal exclusively with the dissemination of knowledge on the physics of the highly-energized particles (I purposely avoid the use of the debatable word "fundamental"). An equal amount is promised by the U.S.S.R., and the service is to be under the auspices of CERN and the International Union for Pure and Applied Research. The other interesting new enterprise, long overdue, is the new journal "Nuklearmedizin," announced by the Friedrich-Karl Schattauer-Verlag, of Stuttgart. To be devoted to the application of radioisotopes and radiations in medicine and biology, this publication will cover a field sadly neglected by most other journals.

Aldermaston's TANDEM Van der Graaf Accelerator

Inside the pressure vessel looking up the accelerating tube

A NEW and important tool for fundamental research into nuclear physics has recently been put into operation at the United Kingdom Atomic Energy Authority's Weapons Research Establishment at Aldermaston. It is a 12 MeV Tandem Van der Graaf Accelerator—the largest of its kind in the world. It will enable Authority scientists to enlarge their survey into nuclear elements to higher energies and thus explore heavier nuclei whose high energy charges would repel the low energy particles obtained in smaller machines.

The new apparatus is installed in the Establishment's nuclear physics research division, together with two simple Van der Graaf accelerators and a Cockcroft-Walton machine. The division was established in 1955 for the purpose of obtaining certain data required for the weapons research programme. As such data is of a fundamental nature and of application in fields other than weapons research the work carried out by the division is unclassified and the equipment installed outside the main Aldermaston security fence.

The Tandem Van der Graaf was designed by Establishment staff in collaboration with the AERE, Harwell, and the Metropolitan-Vickers Electrical Co., Ltd. Cost of construction is estimated at about £200,000, which does not include cost of experimental and developmental work involved. A similar machine of the same capacity is being installed at Harwell.

The purpose of a Van der Graaf is to produce a directed beam of charged particles of controllable energy, the beam being directed on to a target for the purpose of examining nuclear reactions. The low energy machines consist basically of an ion source and accelerating tube. Gas is led into a small vessel at the top of the machine at a low pressure ($\sim 10^{-2}$Hg) and ionized by a radio-frequency discharge. The particles (protons, deuterons or alpha particles, depending upon the gas used) are directed through an exit channel in the ion source by a positive voltage of about 2 kV. After suitable focusing they enter a long evacuated accelerating tube in which the pressure is maintained at about 10^{-5} mm by high speed diffusion pumps.

Applied to this tube is a stabilized voltage of several million volts, positive at the ion source end and earthed at the other. This arrangement accelerates the positive protons to the required energy. They emerge at the other end into an evacuated tube and are then passed through a resolving magnet before being directed on to a target.

Needles Play Part

The voltage is produced by an electrostatic process. An endless belt is rotated at high speed within the height of an insulated stack, a charge being induced on the belt by means of a "comb" of needles placed at the lower end of the belt.

The maximum voltage that can be reached in a system of this type of

Peaceful work at the A.W.R.E.

Although the Atomic Energy Authority's centre at Aldermaston is primarily concerned with weapons research and development much of the work carried out there has peaceful applications and is accordingly declassified. Data obtained from experiments using the machines described in this article, for instance, will be of great use to nuclear physicists generally engaged in reactor studies and in other fields, and will be available to them through the Authority's information facilities.

Other work of this nature includes:—

The development and fabrication of plutonium/aluminium alloy fuel elements—500 of these have already been made and some of them are being tested in GLEEP at Harwell. Later, batches of them will be used in DIDO;

The study of beryllium technology—sintering of the metal without pressure, cold pressing and welding processes, and the development of processes for improving beryllium's high temperature properties;

Purification of beryllium—an attempt to improve the metal's ductility;

Instrumentation development—fast oscillographs and very fast cameras have been developed as a result of requirements of bomb research;

Plasma physics research—various apparatus, including a "pinch" machine, for thermonuclear reaction research are in use;

A theoretical study of the use of nuclear explosions for civil engineering projects and oil separation;

Construction of research reactor HERALD, a light water moderated type which will be used for providing among things intense beams of thermal and epithermal neutrons for general nuclear physics experiments.

reasonable size is about 6 MW and the stability attainable is about 2 kV With the Tandem accelerator, which is a modification of the simple type machine, it is possible to obtain beams of charged particles up to 12 MeV energy.

The principle upon which it operates is as follows: if a neutral hydrogen atom travels relatively slowly (less than 50-100 keV) and passes through a gas, an electron belonging to one of the atoms of the gas is quite likely to stick to the hydrogen atom, giving a negative hydrogen ion, H^-. This sticking tendency is so high at low energies that a positive hydrogen ion can even be transferred into a negative ion by the double capture of electrons. If the speed of the atom or ion is increased much above 100 keV, the " sticking probability " becomes very much less, and the probability of the converse process (double electron loss converting H^- to H^+) becomes quite high—that is, at low ion speeds an electron sticks easily, while at high ion speeds, an electron is knocked off easily.

If a beam of low energy negative hydrogen ions is injected into one end of an accelerating tube earthed at both ends with a potential of (say) +6 MV at its middle, the negative ions will be accelerated to an energy of 6 MeV at the centre of the tube. If a thin foil or a tube containing gas at low pressure is placed at this point, most of the H^- ions will be stripped of electrons and converted to H^+ ions or neutral atoms. The neutral atoms drift on at 6 MeV without acquiring more energy, but the stripped ions, now positive, are further accelerated down the second half of the tube to reach a total energy of 12 MeV at the bottom.

Other Nuclear Apparatus

Nuclear machines installed at Aldermaston in the nuclear physics division, in addition to the 12 MeV Tandem electrostatic generator, are:—

A 6 MeV electrostatic generator manufactured by High Voltage Corporation, of America, capable of giving up to 60μA of protons, deuterons or alpha particles at 6 MeV energy, stabilized to within ±2 kV;

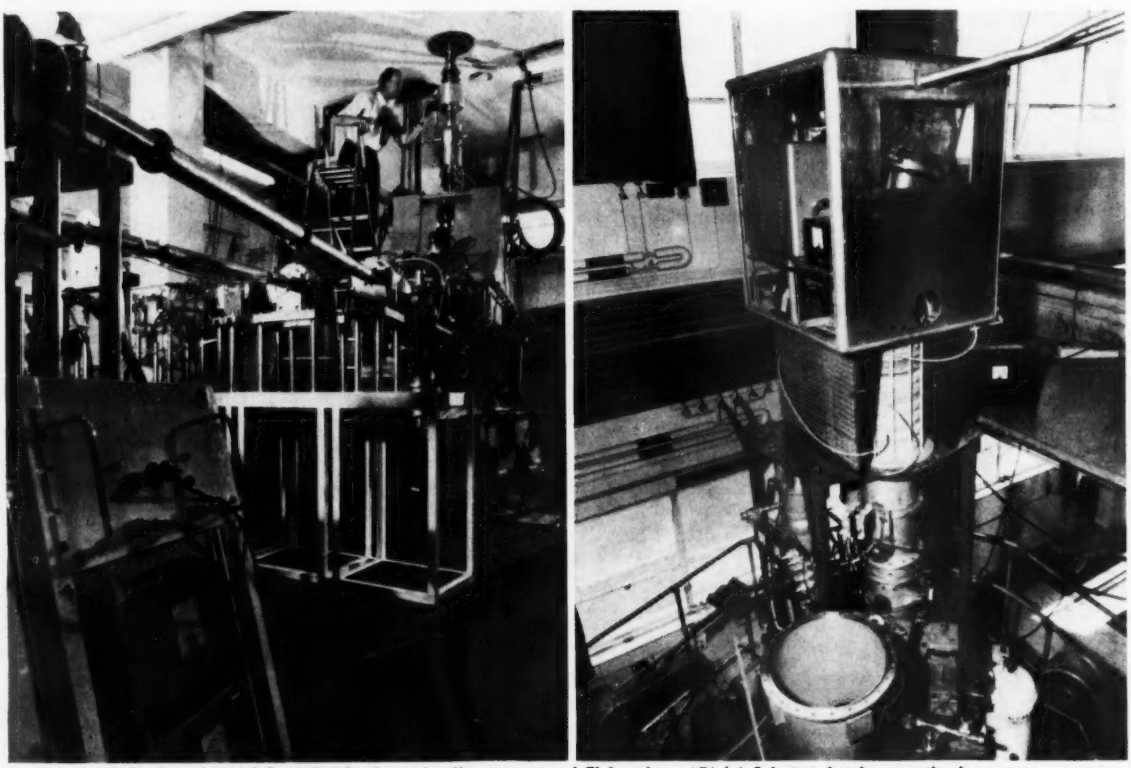
A 3 MeV electrostatic generator of the same make, capable of giving up to 60μA of protons, deuterons or alpha particles at 3 MeV energy, stabilized to within ±2 kV; and

A 800 kV Cockcroft Walton machine constructed by Phillips Ltd., of Eindhoven, capable of giving up to ¼mA deuterons, at an energy stabilized to within ±2 kV. KeV.

External Ion Source

In the AWRE Tandem, the negative ions are produced in a large ion source, situated outside the top of a pressurized tank, down the length of which runs the evacuated accelerating tube into which the ions are introduced. An electrostatic generator runs up the lower half of the stack, so that the half-way point can achieve voltages of up to +6 MV. Inside the vacuum tube at this point is a " stripper " consisting of a tube $^3/_{16}$ in. internal diameter and 24 in. long, into which gas is continually allowed to stream at a rate of 5 cm^3/hr. By pumping hard at either end of the tube, it is possibie to preserve the vacuum in the main tube at between 5×10^{-5} mm and 5×10^{-6} mm, while the pressure in the stripper is kept at an average of 0.02 mm. This concentration of gas, while retarding

(*Continued on page 377*)



(*Left*) **Experimental floor showing beam bending magnet and flight tubes.** (*Right*) **Injector showing negative ion source**

PEOPLE... in the NUCLEAR NEWS

The International Atomic Energy Agency has appointed **PROFESSOR ARKADY N. RYLOV,** of the U.S.S.R. Central Atomic Energy Utilization Board, deputy director general of the Agency's training and technical information department. He succeeds **PROFESSOR V. MIGULIN,** who is returning to his duties at Moscow University, where he is deputy dean of the Faculty of Physics. Born in 1911, Professor Rylov was for seven years senior lecturer and assistant professor of the department of general physics at Moscow University. He then became head of the mathematics department of Yakitia State University, which post he held for five years before becoming professor of Moscow University and of the Moscow Bauman Higher Technical School in statistical and nuclear physics and quantum mechanics.

Marconi Instruments, Ltd., have appointed **MR. ROBERT L. COGDALE** as their European technical representative, resident in Paris. The establishment of this post will lead to greater co-ordination of sales activities in the area and in particular will reinforce the company's position in the countries forming the European Common Market. Mr. Cogdale joined Marconi Instruments in 1941. After working in various technical departments dealing with production, testing, service, installation, maintenance and development, he was transferred in 1949 to the export department.

New domestic sales manager of the American Babcock & Wilcox Company's boiler division is **MR. JOHN G. MARTIN,** who is succeeded as Cincinnati district manager by **MR. WILLIAM E. BUTLER.** Mr. Martin, born in 1907, has been with Babcock & Wilcox since 1929, when he joined the company straight from the Stevens Institute of Technology as a student engineer.

DR. E. C. CREUTZ, director of the John Jay Hopkins Laboratory for Pure and Applied Science, and director of research of the General Atomic Division of General Dynamics Corporation, has been appointed a vice-president of the division. The John Jay Hopkins Laboratory is administered by General Atomic. Dr. Creutz, who has been research director since 1955, was formerly head of the department of physics and director of the nuclear research centre at the Carnegie Institute of Technology, Pittsburg. Another new vice-president of General Atomic is **MR. H. B. FRY,** director of administration. Previously he was manager of the USAEC New York Operations Office and before that assistant manager of the Commission's Albuquerque Operations Office. A third vice-presidential appointment has gone to **MR. C. A. ROLANDER, Jr,** who will be responsible for development programmes.

SIR JOHN COCKCROFT, OM, KCB, CBE, FRS, has accepted an invitation to become one of the trustees of the Isaac Wolfson Foundation. This completes the board of trustees, whose number is limited to nine under the trust deed. The existing trustees are: The Right Hon. The Lord Nathan, PC, TD, PRGS, FSA (chairman), Mr. Isaac Wolfson, The Right Hon. The Lord Birkett, PC, Sir Stanford Cade, KBE, CB, FRCS, The Right Hon. The Lord Evans, GCVO, MD, FRCP, Professor A. L. Goodhart, KBE, QC, FBA, Mrs. Isaac Wolfson, and Mr. Leonard Wolfson. Sir John Cockcroft is shortly taking up his duties as the first Master of the new Churchill College at Cambridge, to which a donation of £70,000 by the Isaac Wolfson Foundation was announced early in April. He is to relinquish his present position as Member for Scientific Research on the U.K. Atomic Energy Authority, which he has occupied since 1954, but will remain a part-time Member of the Authority.

Manchester University's first Professor of Nuclear Engineering is to be **MR. WILLIAM BATEMAN HALL,** BSc(Hons), deputy chief scientific officer in the research laboratories of the Atomic Energy Authority at Sellafield. The chair, which is believed to be the first of its kind in the North of England, has been instituted in the university's department of engineering of the Faculty of Science. It carries a minimum salary of £2,300 a year. Mr. Hall, who is 35 years old, was educated at Urmston Grammar School. In 1939 he joined the Manchester Ship Canal and five years later went to the Royal Aircraft Establishment at Farnborough to work on instrument design. In 1946 he became technical engineer on the staff of the Division of Atomic Energy, Ministry of Supply and until 1951 was engaged on the technical study of nuclear energy plant. At this time he studied for a London University external degree in engineering, which was awarded to him in 1950 with first class honours. In 1951 he transferred to the research and development branch of the UKAEA and became responsible for heat transfer experiments and the investigation of problems associated with liquid metal coolants.

I.A.E.A. News

Uranium Pact

THE Board of Governors of the International Atomic Energy Agency recently approved draft agreements between the Agency and the U.S.S.R., the U.K., and the U.S.A. for the supply by these countries of nuclear materials to the Agency. The offers of supplies were originally made at IAEA's first General Conference; the recent draft agreements incorporate the basic terms and conditions under which these materials are to be made available to the Agency. The materials will be retained by the supplying countries until needed. The U.S.S.R. has agreed to make available 50 kg of U-235, in any concentration up to 20 per cent., in metallic form or in chemical compounds or as fabricated fuel elements. The prices will be based on a scale of charges corresponding to the lowest international prices in force at the time of delivery. The U.K. is to supply 20 kg of U-235 at a price and on conditions that are not less favourable than any of those offered by the U.K. Atomic Energy Authority to other external customers. The material may be supplied in any concentration up to 20 per cent. enrichment in the 235 isotope; there is also provision for higher enrichment for specific research purposes. The U.S.A. will supply 5,000 kg of contained U-235 together with such additional quantities of nuclear materials as will match in amount the total of all supplies of these materials by other members of the Agency prior to July 1st, 1960. The supplies will be made at the U.S. Atomic Energy Commission's published charges applicable to domestic distribution of such materials. In addition supplies may also be made without charge for research on peaceful uses or for medical therapy up to a quantity not exceeding in value $50,000 a year.

Medical Reactor

THE first medical research contract to be placed by the International Atomic Energy Agency has been given to the Department of Clinical Therapeutics of the University of Athens for work on the diagnosis of certain diseases with the aid of radio-isotopes. The investigations are expected to help in the treatment of echinococcus, a parasitic disease which forms cysts in the lungs and the liver, and of certain types of anaemia. These disorders are very common in Greece as well as in several other sub-tropical regions of the world. Clinical research work on these disorders has already begun at the Isotope Laboratory of the Alexandra Hospital in Athens. The research contract placed by IAEA is meant to assist and expand this work by providing funds for materials and for scientific and technical personnel. The Agency will provide nearly U.S.$8,000 for the project.

Isotope Centres

THE International Atomic Agency is to make a study of problems involved in the setting up of one or more isotope training centres in Arab and other countries in Africa and the Middle East. It has been suggested that existing facilities at Cairo and Ankara should be used as a basis for these centres.

The National Bureau of Standards is studying the interaction of X-radiation with matter to determine the shape of the nuclei involved in the process. The technique used, which involves cross-section measurements, makes the effects of nuclear deformation immediately evident. Splitting or broadening of the giant resonance line is detected and can be directly related to the nuclear shape

SHAPE OF ATOM NUCLEUS

RECENT work carried out at the U.S. National Bureau of Standards shows that the energy dependence of the nuclear photon-absorption cross section can be directly related to the shape of the atomic nucleus.[1] This approach to the determination of nuclear shapes developed out of investigations of the interactions between high-energy electromagnetic radiation and matter. One such interaction is the nuclear photoeffect —the absorption of high-energy photons by the nucleus.

Recent measurements of the total nuclear absorption cross-section—the probability that photons will be absorbed—indicate that the cross-section curve depends in part on the intrinsic nuclear quadruple moment. Classically this dependence means that the absorption of high-energy electromagnetic radiation by the nucleus is influenced not only by the finite size of the nucleus but also by its shape.

Noted in 1944

The finite extent of the nuclear charge distribution was originally demonstrated by the alpha-particle scattering measurements made by Lord Rutherford in the 1920s. Probably the first suggestion that this charge distribution lacked spherical symmetry was made in 1944 by Brix and Kopfermann to explain irregularities they had observed in isotope shifts for some atomic spectral lines.[2] Soon after this, departures from the interval rule for atomic hyperfine structure were explained by postulating a deformation of the nuclear charge distribution.

At present, information about this deformation is also being obtained from nuclear spectroscopy (measurement of absolute electric quadrupole transition rates and the energy of nuclear rotational energy states); high-energy electron scattering measurements; and spectral studies of μ-mesonic atoms. However, quantitative values for the nuclear charge deformation obtained from these experiments depend also upon detailed knowledge of either atomic or nuclear wave functions. On the other hand, the recent cross-section measurements which were made by members of the Bureau's high energy radiation group, can be correlated directly with the intrinsic nuclear quadrupole moment by the following rather simple classical picture.

In the classical limit, the atomic nucleus may be thought of as a figure of revolution with well defined edges. Its mean radius is given by $R=R_0A^{1/3}$, where R_0 is a constant and A is the mass number of the nucleus. In this limit, for a uniformly charged nucleus, the static quadrupole moment is defined by $Q_0=2/5\,Z(a^2-b^2)$, where a and b are the half axes and Z is the nuclear charge.

A classical model which has been successful in predicting many nuclear properties, particularly with respect to the nuclear photoeffect, pictures the nucleus as compressible neutron and proton fluids contained within rigid boundaries. The electric dipole absorption of electromagnetic radiation by such a nucleus takes place primarily in a single resonance line (the giant resonance) whose energy is inversely proportional to the nuclear radius of a spherical nucleus. It was pointed out by Danos[3] and Okamoto[4] that such a model implies that the giant resonance for the absorption of unpolarized photons by an unaligned, deformed nucleus will split into two resonances, one associated with each of the half axes of the nucleus. This prediction has now been experimentally confirmed in some detail at the Bureau.

The experiment consisted in determining the photoneutron production cross-section for two nuclei which were known to be highly deformed (terbrium-159 and tantalum-181) and for one known to have only a small deformation (gold-197). These cross-sections were obtained from an analysis of the measured neutron yield curves for the three nuclei. A photoneutron yield curve is obtained by bombarding a sample with betatron-produced X-rays and measuring the yield of neutrons as a function of the upper energy limit of the X-ray spectrum. In order to obtain a statistically significant cross-section from such a yield curve, it is necessary that statistical uncertainties be very small. To fulfil this requirement, 0.5 to 1.2 million neutron counts were recorded at each significant point on the neutron yield curve; the yield was measured every 0.5 MeV from 7 to 20 MeV.

Predictions Confirmed

The resulting photoneutron production cross-sections all showed effects of nuclear deformations, as predicted. The giant resonances for *Tb* and *Ta* were split into two resonances while that for *Au* was merely broadened. The quadrupole moments evaluated from these data are in very good agreement with the best previously determined values, demonstrating the applicability of this approach.

References

[1]FULLER, E. G., PETREE, B., and WEISS, M. S., "Photoneutron Yields in the Rare Earth Region." *Phys. Rev.* 112, 554 (Oct. 15th, 1958); FULLER, E. G., and WEISS, M. S., "Splitting of the Giant Resonance for Deformed Nuclei." *Phys. Rev.* 112, 560 (Oct. 15th, 1958).

[2]*Z. Physik* 126, 344 (1944).

[3]*Bul. Amer. Phys. Soc. Ser. II, No.* 1, 135 (1956).

[4]Progress of Theo. Phys. Japan 15, 75 (1956).

NUCLEAR NEWS

- ***Dreadnought* Keel Laid** *(First item)*
- **U.K.A.E.A. Safety Courses** *(Page 374)*
- **O.M.R. as Economic Unit** *(Page 375)*

Duke Lays Keel

THE keel of Britain's first nuclear powered submarine, *Dreadnought*, was laid recently by Prince Philip, the Duke of Edinburgh. The ceremony took place at Vickers-Armstrong's shipyard at Barrow-in-Furness. Associated with the construction of the submarine are Vickers, Ltd., Foster Wheeler Ltd., and Rolls-Royce, Ltd. The propulsion machinery is to be supplied from America. The reactor will be similar to that used in the U.S. Navy's *Skipjack* class of submarines.

Nucleonic Patents

ACCORDING to the recently published annual report on patents, designs and trade marks, there has been an increased interest over the past year in the use of radioactive substances for controlling industrial processes. There was also a marked increase in patented specifications relating to nuclear reactors. Over 100 specifications in nucleonics were accepted by the Patents Office in 1958, compared with fewer than 50 in 1957.

Nuclear "Take Over"

THE commercial nuclear engineering interests of ACF Industries, Inc., of New York, have been bought up by the Allis-Chalmers Manufacturing Co. About $10m. worth of contracts for the design and construction of power, test and research reactors are involved. The purchase price has not been revealed. The acquisition broadens Allis-Chalmers participation in the nuclear market not only on account of ACF's contracts but through the acquisition of a team of distinguished scientists, engineers and technicians. The ACF chairman, Mr. W. T. Taylor, has stated that his company had sold the commercial side of their nuclear business because " it has become evident that future rewards in the commercial reactor field will accrue principally to companies dominant in the power equipment industry." He added that ACF would concentrate its nuclear energy effort in its Albuquerque division, which operates some of the larger facilities of the U.S. Atomic Energy Commission's weapons production units. Allis-Chalmers manufacture a wide variety of power and electrical distribution equipment and has been active in the nuclear energy field for the past 15 years. The company is responsible for the design, development and construction of the recirculating boiling water reactor plant planned for Sioux Falls and for the design and construction of the Stellarator thermonuclear assembly operating at Princeton University, New Jersey.

Israel's Reactor

ISRAEL'S first nuclear reactor, designed for research and the training of operators, is expected to be in action early next year. In charge will be Dr. Y. Pelah, who studied in Amsterdam, Brookhaven and Jerusalem. The reactor is being installed now, south of Tel Aviv. The Israel Atomic Energy Commission is responsible for the construction of the building, while the $350,000 reactor itself—of the " swimming-pool " type—is being provided by the U.S. Government in the form of a special grant, and supplied by the American Machine & Foundry Co. The Israel Government is spending the equivalent of $450,000 on the building, etc. The construction work is undertaken by the Solel Bonch contracting corporation. The reactor is capable of producing up to 1,000 kW of heat energy, which can later be increased to 5,000 kW. It will be used to train young Israelis in the care and operation of nuclear equipment and will be available for the use of all research institutions in Israel, and later for scientists from other countries.

G.E.C. German Pact

The General Electric Co., Ltd., of England, have concluded an Agreement with Maschinenfabrik Augsburg-Nurnberg A.G. (M.A.N.) of Germany for the interchange of nuclear patents. The Agreement was signed by Herr Ulrich Neumann (*centre*), director general of M.A.N., Mr. Arnold Lindley (*second from left*), assistant managing director of GEC, Herr Hans Fischer (*extreme right*), of M.A.N., and Mr. R. N. Millar (*second from right*) of GEC

U.K.-Euratom Committee

THE British Government and the Euratom Commission have agreed to establish a continuing committee to supervise the operation of the U.K.-Euratom Agreement which was concluded on February 4th. The purpose of the committee will be to provide a forum for consultations on matters arising out of the application of the Agreement and for discussions on the possibility of additional arrangements for co-operation. It will consist of a U.K. Minister and the chairman of the UKAEA and the chairman and another member of Euratom. It will meet from time to time at the request of either side. The continuing committee will be assisted by a technical committee, which recently held its first meeting. Members of the technical committee are Mr. J. Gueron, Mr. E. Staderini, and Mr. E. G. Stijkel, of Euratom, and Dr. J. V. Dunworth, Mr. J. B. W. Cunningham and Mr. D. E. H. Peirson, of the UKAEA.

Pu Exchange Pact

AN Agreement for the exchange of plutonium and enriched uranium between the United Kingdom and the United States has been signed. Britain will supply the plutonium, America the uranium. The Agreement also covers the exchange of components of U.K. and U.S. nuclear weapons other than the actual warheads. The essence of the pact is that it will enable Britain to dispose of the plutonium produced at Calder Hall, Chapelcross and the power stations now under construction. The Agreement is for an indefinite length of time.

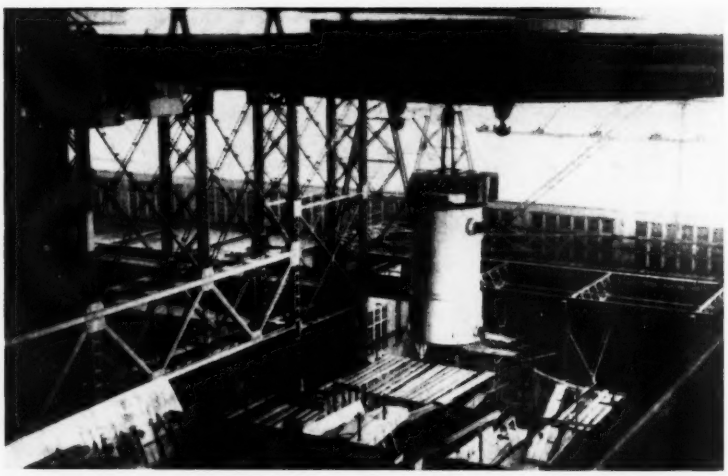
U.K.A.E.A. Safety Courses

PRELIMINARY plans to extend knowledge of dealing with radioactivity and to train the specialists needed to deal with radiation hazards have been announced by the United Kingdom Atomic Energy Authority. The problem of national needs in this field has been under consideration since June, 1958, by a committee on training in health and safety appointed by the Authority with Sir Douglas Veale, formerly Registrar of Oxford University, as chairman. This step was taken following recommendations made by one of Sir Alexander Fleck's Committees set up by the Prime Minister after the Windscale accident. Two interim reports have already been given to the Authority by the Veale Committee. The final report is expected later this year. The first interim report recommended special post-graduate courses at universities to train graduates in science or medicine to undertake specialist posts in the field of radiological health and safety. It is expected that two such courses will be available in London University by October this year, one run by the Royal Marsden Hospital and the other by the Middlesex and St. Bartholomew's Hospitals, jointly. The possibility of similar courses at Birmingham and Edinburgh Universities and the Royal Technical College, Salford, is also being discussed. The second report recommended a summer school to be held this year at Oxford for people who, although not engaged on full-time health and safety duties, need some knowledge of the problems involved. Invitations to attend the course, which will be at New College in August and will be sponsored by the Oxford Extra-Mural Delegacy and the Atomic Energy Authority, are being sent to candidates sponsored by Government departments or official organizations. It is regarded as a " pilot " scheme and because of this and the fact that numbers will be limited, it will not be possible to accept individual applications. Those invited are expected to include medical officers of health, local government officers, hospital administrators, some senior civil servants and representatives of industrial managements.

Use of Plutonium

PLUTONIUM-239 is being used by General Motors of America to measure the moisture content of moulding sand in their foundry. It is believed that this is the first industrial application of its kind. The technique utilizes fast neutrons emitted from 32 g of plutonium mixed with beryllium powder and sealed in a stainless steel capsule. Fast neutrons collide with the hydrogen nuclei in water molecules in the sand, producing slow neutrons that can be counted electronically. The number of slow neutrons is directly proportional to the moisture content of the sand.

Ready for Savannah



The 105-ton reactor pressure vessel for *NS Savannah*, the world's first nuclear-powered passenger cargo ship, being lowered into the containment shell located amidships. The whole of the ship's propulsion unit is being supplied by Babcock and Wilcox, of America. Launching of the *Savannah* is due to take place on July 21st

Fifth Continental

FRANCE, S.A., another new associate company of the Solartron Electronic Group, Ltd., of Thames Ditton, is now in process of formation. Already substantial orders have been booked and negotiations are in hand with a leading French manufacturer concerning the manufacture in France of certain types of Solartron precision electronic equipment. Other Solartron companies are Solartron G.m.b.H. (Munich), Solartron S.r.l. (Milan), Solartron NV. (The Hague), and AB Solartron (Stockholm).

At Hinkley

The 650-ton Goliath crane at the Hinkley Point nuclear power station site. It has a span of 250 ft and height of 235 ft and is said to be the world's largest. It will be used for lifting heavy major pieces of equipment into place and was built by Babcock and Wilcox, a member of the group responsible for the construction of the station

French-U.S. Pact

FRANCE is to buy enriched uranium fuel for a prototype nuclear propelled submarine from the United States under an Agreement recently signed between the two countries. France will be able to buy up to 440 kg of uranium within 10 years from the time the Agreement comes into force.

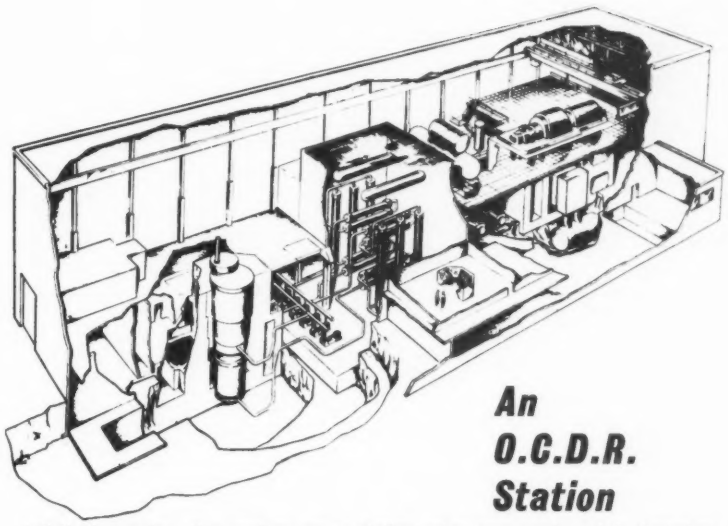
H. & V.R. Council

CONSULTING Engineers who have already joined the Heating and Ventilating Research Council will know that it has now been officially recognized by the DSIR and will be pleased to hear that it is now a full constituted corporate body. It has been promised a substantial annual grant for 5/7 years, and a contribution of half the cost of building the Research Station, the construction of which has already begun at Bracknell. There are at present about 30 firms who have joined the Research Association but there are many more Consulting Engineers in practice in heating and ventilating who are not yet members and also a number of larger firms whose work includes heating and ventilating. At present the total subscription of the Consultants' group is only enough to qualify for one representative on the Executive Committee who is at the moment Mr. H. E. Baker. We feel that Consulting Engineers ought to be represented by at least one more member to help with the business and representation on various panels. Also the Consultants generally should take a bigger share in the investigations and formulating of proposals for future research. Anyone interested should get in touch with the Research Association's Secretary at the temporary address at:—BCURA Laboratories, Randalls Road, Leatherhead, Surrey.

Economic Proposition

COMPETITIVE nuclear power in a few years using an organic cooled and moderated reactor of 300 MW electrical output is indicated in a report by the Bechtel Corporation and Atomics International, a division of North American Aviation, Inc. The report is one of four recently made available for public review by the U.S. Atomic Energy Commission. Bechtel prepared the report as part of a study contract with the commission to develop designs for organic cooled reactor power plants. Atomics International, as a sub-contractor to Bechtel, are responsible for design of the nuclear reactors. Results of the study indicate that a large organic cooled and moderated central station atomic power plant could be expected to show generation costs of 8.1 mills/kWh at an 80 per cent. plant capacity factor. This includes all costs such as escalation and interest during construction. The study also determined that a promising concept for an intermediate sized plant was an organic cooled and moderated reactor of 75,000 kW electrical output. Construction estimates, schedules and operating expenses were established for a hypothetical site.

An O.C.D.R. Station



Artist's impression of a nuclear power station using an organic-cooled, deuterium-moderated reactor of the type which is to be designed and developed for the Atomic Energy of Canada, Ltd., at Chalk River by the Canadian General Electric Co. Research into the use of organic coolants has been conducted by AEC, Ltd., in the NRX reactor at Chalk River. Unlike the organic-cooled and moderated reactor, which uses enriched uranium as fuel, the OCDR will use natural uranium

Institute Enlarges

A THREE-STOREY laboratory block has been added to the Hungarian Academy of Sciences' Nuclear Research Institute at Debrecen, at a cost of £270,000. Housed on the ground floor will be an 800,000v cyclotron, at present under construction. Set up only five years ago, under the directorship of Dr. Sandor Szalay, the Debrecen Institute has already attracted international scientific attention by photographing for the first time the recoil, or "bounce," of the neutrino, which yielded valuable information about the nature and behaviour of the forces working inside the atomic nuclei. On the third floor of the new laboratories a spectrograph is being installed to study the age, structure and isotope proportions of meteorites falling from space.

Progress at Italian Site

View of the site of the Latina nuclear power station, Italy, during April. In the background is the reactor fabrication area and the two legs of the Goliath crane. Construction of the station is a joint enterprise between AGIP Nucleare and the Nuclear Power Plant Co., Ltd.

Go-devil Safety

SAFETY precautions for workers who may be exposed to ionizing radiations arising from the inclusion of radioactive markers in "Go-devil" devices for the detection of obstructions in pipelines are set out in a new booklet, *Radioactive markers in Go-devils; Safety Precautions*, recently published by the Ministry of Labour and National Service. "Go-devils" consist of tightly fitted rubber washers, scraper vanes or wire brushes mounted on a central core. They are frequently used by oil, gas, water and other industries for detecting whether newly laid mains are free from obstruction, and also in the routine maintenance of existing pipelines. "Go-devils" are pushed through pipelines by means of water or compressed air, and they occasionally get jammed against an obstruction. Location of the cause can be an expensive procedure, involving excavations over a considerable length of pipeline. The inclusion of a radioactive marker in the central core, which is exposed on contact with an obstruction, will overcome the difficulty because the gamma rays given off by the radioactive material can be readily traced above ground. The use of radioactive substances in these devices requires the observance of strict precautions to avoid hazards which arise, and a Code of Practice for persons engaged in such operations is set out in this publication.

New Offices

DOMINATING the approaches to Olympic Way at Wembley Park, Middlesex, are the new administrative offices of the aviation, Marine and Industrial divisions of S. Smith & Son (England), Ltd., which occupy a site which at the time of the 1924 exhibition was a lake and gardens. The building cost approximately £250,000.

Equipment and Materials

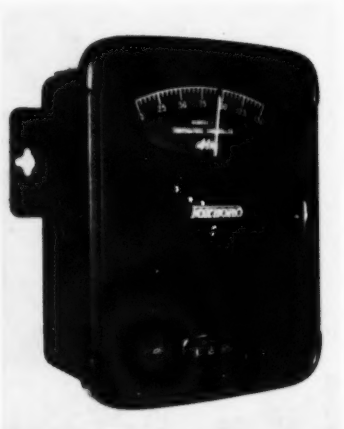
Items published in this special feature are compiled from manufacturers' current literature. Readers requiring further information should use the form at bottom of the page. Manufacturers are invited to send literature or details of their products for inclusion in this feature.

Valve-Voltmeter

The Winston Valve-Voltmeter, designed and manufactured by Winston Electronics, Ltd., measures direct and alternating currents of circuits without bleeding the circuit under test. The instrument presents a very high impedance to the circuit under test. The valve-voltmeter is housed in a fibreglass reinforced plastic case, whose insulation is better than 100 megohms. The case also has excellent mechanical strength. The capacity of the probe is so small, less than 5 pF, that no part of the signal at high frequencies is shunted from the circuit under test. The a.c. probe uses the latest silicon junction diodes. The meter scale is 5 in. (12.5 cm) long and has a mirror. It may also be used as a centre zero reading valve voltmeter. **(JY 1).**

Indicating Controller

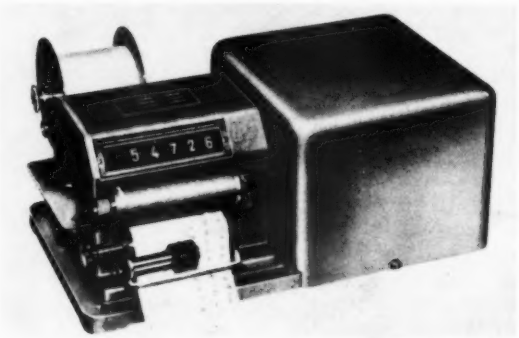
Foxboro-Yoxall, Ltd., have introduced a new air-operated indicating controller, the M/41A. This new addition to their range of rectangular cased indicator controllers and recorders provides on/off or proportional action for pressure, temperature, relative humidity or open tank liquid level applications. It is also made as a pneumatic receiver for 3-15 lb/sq.in. signals. Standard Foxboro components are used in the new instrument, which is mounted in a dust- and moisture-proof cast aluminium case. A specially developed control unit provides on/off action to one-eighth of 1 per cent. scale range. The pneumatic proportioning mechanism—fully adjustable from one-quarter of 1 per cent. to 25 per cent. of the scale—provides ample range for a wide variety of simple applications. The M/41A controller is easy to install and operate. Surface, flush, yoke or valve mountings are available and all operating adjustments are easily accessible. **(JY 2).**



Air-operated indicating controller made by Foxboro-Yoxall, Ltd.

Counter/Printer

A new electro-mechanical counter has been designed by Radiatron which will provide a permanent printed record of a variety of measurements. It is available in various models to suit different applications. These include the counting of electrical impulses or closures of a switch up to a speed of 5 per sec, the recording of elapsed time in units of 0.01 min or in seconds, and the counting of revolutions of a shaft up to 50 per sec. The count is printed in numbers of up to six digits on a paper roll $2\frac{3}{8}$ in. wide or on cards. An automatically changed serial number or hand-adjusted code, consisting of two figures or letters can be printed in addition to the counting digits. All characters of the code and digits are printed simultaneously. The printing counter is a compact instrument occupying a volume less than 11 in. in length, 6 in. in width and $4\frac{1}{2}$ in. in height, and weighing approximately 11 lb. It is therefore suitable for building into automatic control panels and measuring equipment. It can be supplied with fully automatic action or with a hand-operated lever; the printing, paper shifting and resetting operations being performed automatically in a total time of 1 sec by means of an incorporated torque motor energized by an electrical impulse. The digital printing counter is a very versatile



Radiatron's new electro-mechanical counter

Cut along here

To: **NUCLEAR ENERGY ENGINEER**
147 Victoria Street, London, S.W.1

Please send further details of the following items in the EQUIPMENT and MATERIALS *feature for July, 1959*

Item No's ....
....

IS THIS ENQUIRY CONFIDENTIAL? YES | NO

Enquirer's Name .....
Position .....
Firm .....
Address .....

instrument. Its application in industrial processes, in addition to batch and revolution counting, includes the recording of any variable or the time integral of such a variable in automatic plant control that can be converted into electrical impulses or rotations of a shaft. Examples are temperature, pressure, flow rate, etc., or the deviation of these from a set value. Several quantities can be recorded by using a sequence controller with the coding facilities of the counter. When used for nuclear particle counting, a scaler with a factor of 100 is normally employed in conjunction with the instrument in order to increase the maximum count rate. Owing to the smoothing effect of the scaler, its paralysis time for random pulses is considerably shorter than the counter dead time (one-fifth second) divided by the scaling factor. For radioactive isotope assay the printing counter is used in its form of a time printer. It is triggered by a predetermined count scaler when a preset number of counts is reached. **(JY 3).**

For Welders

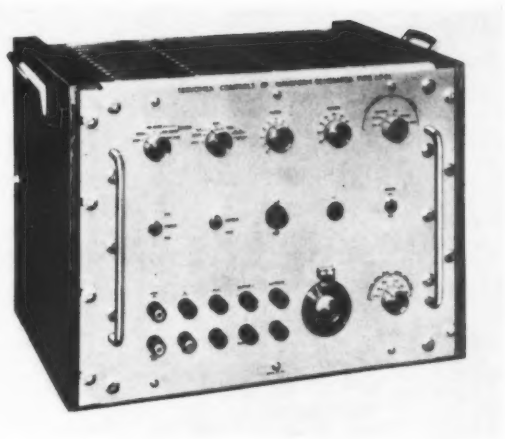
A handy device for any welder is the Rockweld fillet weld gauge. It is square in shape, with sections cut out of all its four corners. These corners, when placed against the surfaces of the welded materials will show the leg lengths of fillet welds. There are four measurements—$^{3}/_{16}$ in., $\frac{1}{4}$ in. $^{5}/_{16}$ in. and $\frac{3}{8}$ in. The throat thickness of the weld can be measured by pushing the pointer of the gauge until it touches the weld. The thickness is then obtained by reading off the calibrated scale. The gauge is about 2 in. square and slips easily into the pocket. It is in anodized aluminium, and is coloured blue with silver markings. **(JY 4).**

Spot Welding Gun

Among the latest additions to the spot welding guns made by Portable Welders Ltd., of Buckingham, mention should be made of the new Farac 200 fan cooled toroidal arc welding transformer and the new Autospot 4.8 kVA machine. Both are designed for maintenance welding. Principal features of the Farac 200 are its high power factor (between 0.8 and 0.9 lagging) and small size (it weighs 78 lb and takes up the space of 14 in. cube). The set can be connected direct to any 200/250 or 400/440v a.c. mains; open circuit voltage of the machine is 50v. The Autospot which is a lightweight portable spotwelder, can be used from any 220/230v a.c. 15-20 amp mains socket and is particularly useful for general maintenance and tack welding. The new version is packed in all-purpose steel case. **(JY 5).**

Test Equipment

A new function generator for testing servomechanisms and automatic control systems has been produced by Servomex Controls, Ltd. This is the low frequency Waveform Generator type L.F.51, with which a comprehensive variety of electrical test signals can be generated over a wide range of frequencies. It is also suitable for use with analogue computers. The waveforms produced by this instrument include sine and square waves, ramp functions, triangular, sawtooth, trapezoidal and sine-squared pulses. Square waves and pulses can be generated with durations of 100 microseconds up to 1,000 seconds while the frequency of sine waves can be varied from 500 cycles down to 0.0005 cycles, the latter being equivalent to one cycle every 33 min. A special feature of the instrument is that a complete cycle or one-half cycle as well as continuous operation can be obtained in all of the above waveforms. The amplitude for all waveforms is variable from 100 microvolts up to 150v, peak to peak, six ranges being provided each on a continuous potentiometer control scaled 0–150 and the absolute accuracy is ± 3 per cent. of the full scale figure. **(JY 6).**



This low frequency waveform generator made by Servomex Controls, Ltd., can be used with analogue computers

Magnetic Holder

Designed for holding work to be welded in position is the Eclipse magnetic holder. Working on the same principle as the Eclipse magnetic base, it is capable of exerting a powerful hold on iron and steel plates, bars or tubes. The magnetic flux is controlled by simply turning a handle, similar to an ordinary water tap. The use of a powerful magnet ensures permanent service and the holder cannot be demagnetized unless dismantled. **(JY 7).**

Nuclear Detection

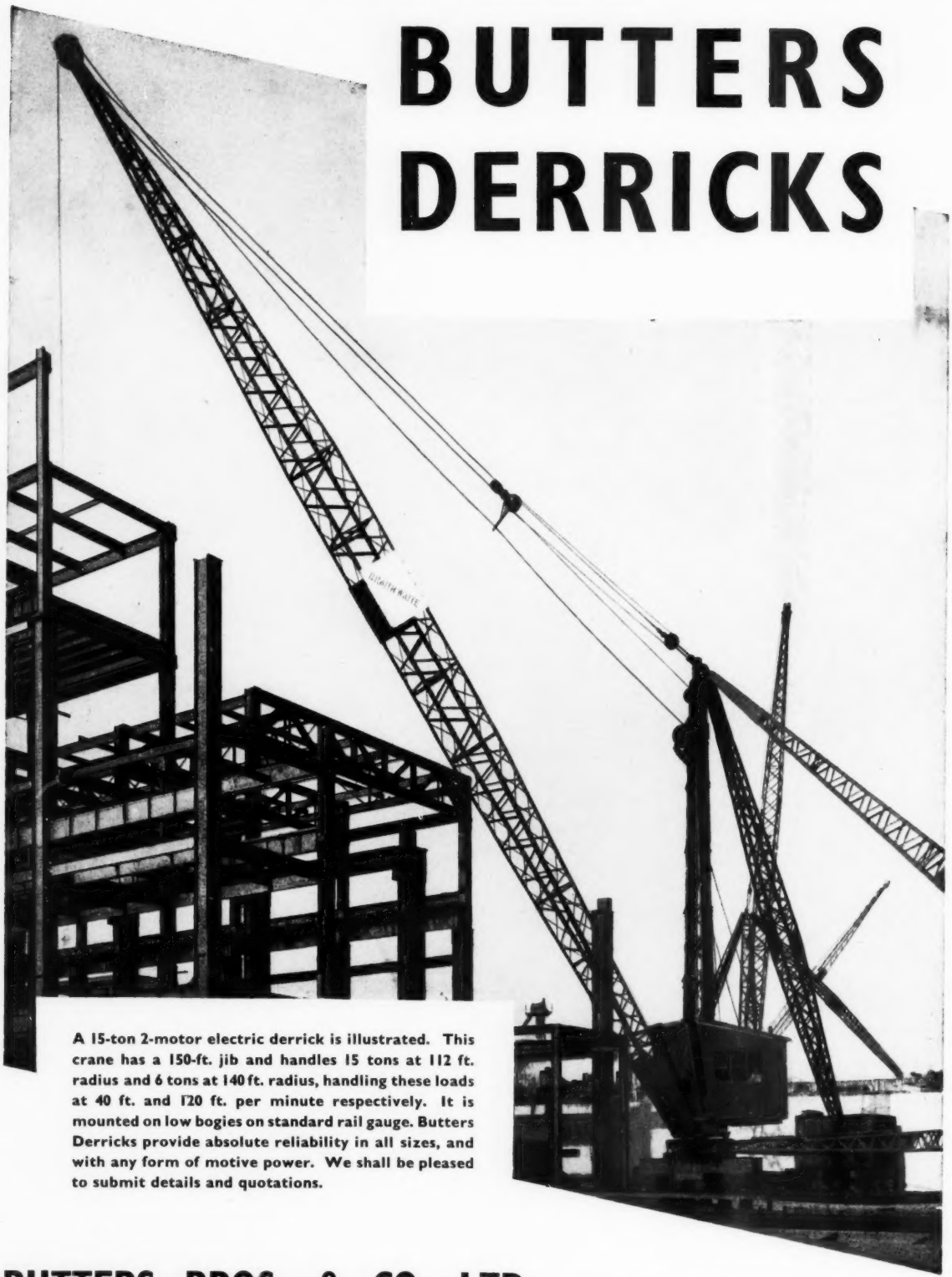
AN electronic tube that can detect a splitting atom or the faintest star has been developed by the Westinghouse electronic tube division. The new tube, an advanced type of image intensifier, amplifies the light entering at one end to produce an image as much as 3,000 times brighter on the fluorescent screen at the tube's opposite end. If four of the tubes were placed in series, says Westinghouse, they would be able to see a candle's light 250 miles away. Most important use of the new device is expected to be in the nuclear field, where it will permit photographic records of atomic particle reactions. Two University of Michigan physicists, Martin L. Perl and Lawrence W. Jones, have already used the tube in a luminescent chamber system to produce what are believed to be the first photographs, outside the U.S.S.R., of light from the path of a single atomic particle. Pictures never before possible can be taken with the tube of the minute light scintillations that occur when certain materials are struck by nuclear particles produced by particle accelerators, according to Westinghouse. The nature of these fleeting scintillations provides data on the nuclear reaction being observed. **(JY 8).**

(*Continued from page 370*)

the fast ions by only an insignificant amount of energy, is sufficient to strip the greater proportion of them and convert them to positive ions. The beam emerging from the negative ion source is focused before entering the accelerating tube, so that the majority of the beam enters the narrow stripper tube, and the beam emerging from the stripper is further accelerated. Experiments are at present being carried out at an energy of up to 10.3 MeV.

Equipment used in conjunction with the Van der Graaf accelerators include time of flight spectrometers, used for measuring the neutron "spectrum," magnetic particle spectrometers for examining particle "spectra" and a large liquid scintillation counter. Among the magnetic spectrometers is a multichannel spectrograph, developed at Aldermaston and the only one of its kind in use. The magnet weighs 13 tons and is in the form of a large ring into which are cut 24 $\frac{3}{8}$ in. air gaps at approximately $7\frac{1}{2}^{\circ}$ intervals. Each gap constitutes a magnetic spectrograph with similar specifications to the single "broad" range spectrograph in use.

BUTTERS DERRICKS



A 15-ton 2-motor electric derrick is illustrated. This crane has a 150-ft. jib and handles 15 tons at 112 ft. radius and 6 tons at 140 ft. radius, handling these loads at 40 ft. and 120 ft. per minute respectively. It is mounted on low bogies on standard rail gauge. Butters Derricks provide absolute reliability in all sizes, and with any form of motive power. We shall be pleased to submit details and quotations.

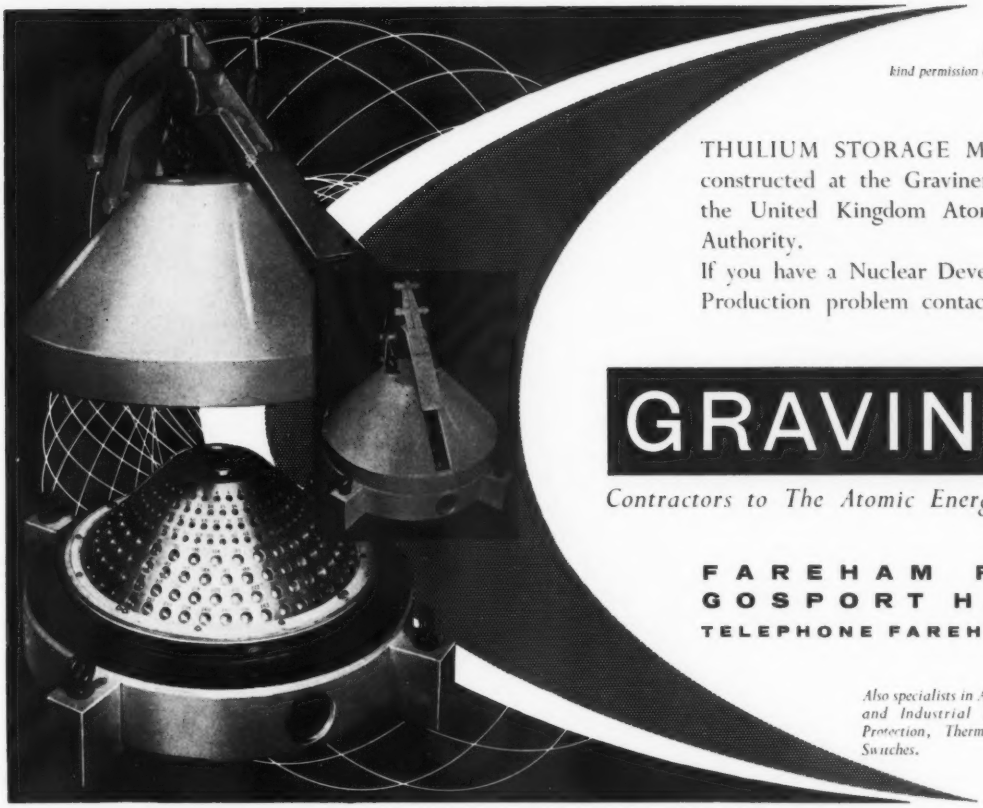
BUTTERS BROS. & CO. LTD.

MACLELLAN STREET **GLASGOW, S.1**

Telephone : IBROX 1141 (6 lines) *Telegrams : "BUTTERS, GLASGOW"*

LONDON : The Crane Works, Long Lane, Hillingdon, Middlesex
Telephone : UXBRIDGE 3925 & 2288

and at BIRMINGHAM and NEWCASTLE



Photographs by kind permission of U.K.A.E.A.

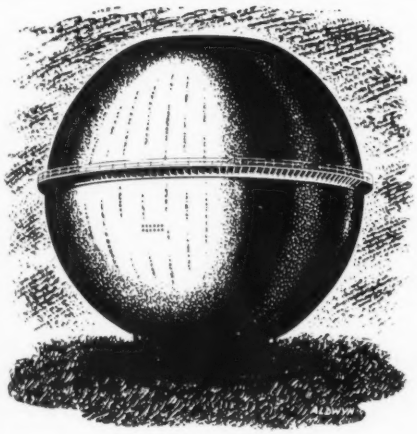
THULIUM STORAGE MAGAZINE constructed at the Graviner works for the United Kingdom Atomic Energy Authority.
If you have a Nuclear Development or Production problem contact us today.

GRAVINER

Contractors to The Atomic Energy Authority

FAREHAM ROAD
GOSPORT HANTS
TELEPHONE FAREHAM 2511

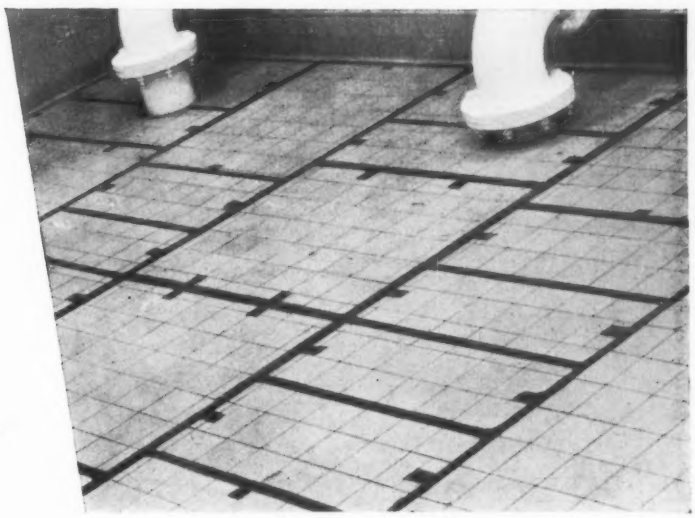
Also specialists in Airborne, Diesel Engine and Industrial Fire and Explosion Protection, Thermostats and Overheat Switches.



into the Nuclear age...

BROADS TRUCAST

CONTINUOUS DUCT AND ACCESS COVERS



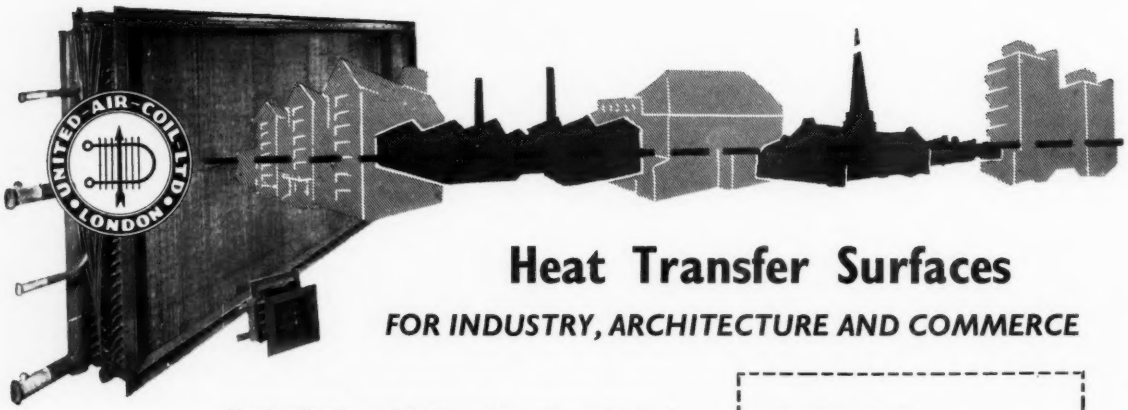
performing many duties in this specialised field

BROADS

MANUFACTURING CO. LTD.

4 SOUTH WHARF · PADDINGTON · W2

TEL: PADdington 7061 (20 lines)



Heat Transfer Surfaces

FOR INDUSTRY, ARCHITECTURE AND COMMERCE

Air Conditioning and Refrigeration engineers frequently require something more than "standard service" in the design and supply of heat transfer surfaces. It is by treating the majority of our jobs as "specials," and by taking considerable pride in ensuring that everything that leaves our factory is 100% up to specification, that we have built up a very impressive list of customers and installations in all branches of industry, architecture and commerce. We welcome any enquiry which demands our standards of thoughtful service and reliable manufacture.

Cooling Coils

Brine, Chilled Water and Direct Expansion Refrigerants—including coils for Solvent Recovery.

Air-cooled Condensers

A wide range of standard models, covering small and large air-flows.

Heating Coils

For all systems, using steam or hot water.

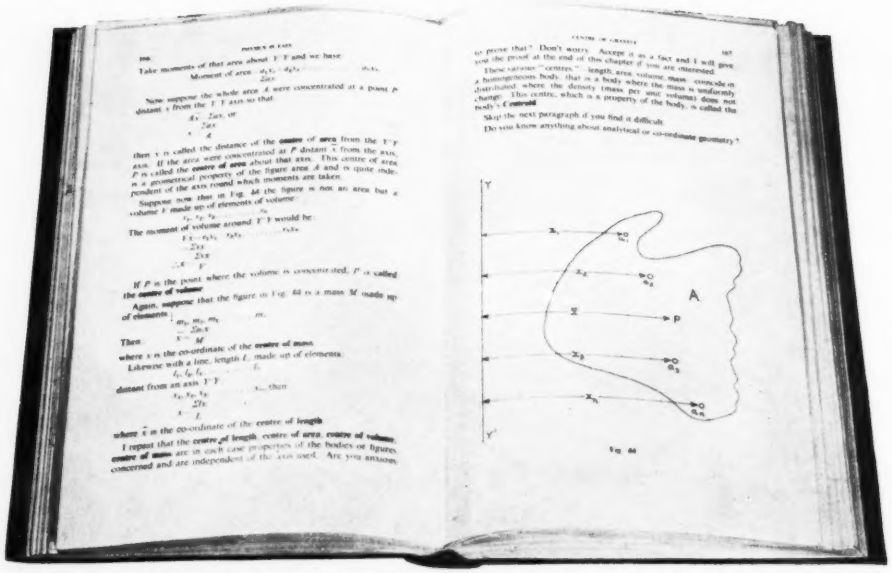
Write for full details of our products and service.

United Air Coil Ltd

13 New Bridge Street, London, E.C.4
Telephone: FLEet Street 2295/6/7
Telegrams: AIRCOILIM LONDON

PHYSICS IS EASY

by D. S. Watt, B.Sc., M.I.N.A.



Size of the Book 8½ in. × 5½ in. and is in blue cloth. 560 pages with 123 diagrams.

Send 63/- (which includes postage) for immediate attention

PRINCES PRESS LIMITED, 147 VICTORIA STREET, S.W.1

PRESSURE VESSELS with a NAME

The name COCHRAN is mainly associated with marine auxiliary and industrial steam boilers of correct design and careful workmanship. The same name attached to a pressure vessel is your guarantee of excellence. Made throughout at Newbie Works, Annan, Dumfriesshire, COCHRAN pressure vessels are built in sizes ranging from 1′ 6″ to 14′ 0″ diameter, 5′ 0″ to 100′ 0″ in length and up to 100 tons in weight.

Send us your pressure vessel enquiries — you will find that our prices are right.

COCHRAN

Cochran & Co., Annan, Limited, Annan, Dumfriesshire, Scotland, and at 34 Victoria Street, London, S.W.1

TAS/CH639

PROCEEDINGS OF THE SECOND UNITED NATIONS INTERNATIONAL CONFERENCE ON THE PEACEFUL USES OF ATOMIC ENERGY

Geneva, September, 1958. ENGLISH EDITION—33 volumes including the following titles:

REACTOR GROUP

*Volume 6	Basic Metallurgy & Fabrication of Fuels, 80 Conference Papers, 770 pages ..	£6 9 0
Volume 7	Reactor Technology, 81 Conference Papers	£7 0 0
*Volume 8	Nuclear Power Plants, Part I, 44 Conference Papers, 584 pages	£5 0 0
Volume 9	Nuclear Power Plants, Part II, 41 Conference Papers	£6 5 0
Volume 10	Research Reactors, 49 Conference Papers..	£6 12 0
*Volume 11	Reactor Safety and Control, 61 Conference Papers	£5 11 0
*Volume 12	Reactor Physics, 55 Conference Papers, 774 pages	£6 12 0
Volume 13	Reactor Physics and Economics, 55 Conference Papers	£6 12 0

CONTROLLED FUSION GROUP

*Volume 31	Theoretical & Experimental Aspects of Controlled Fusion, 50 Conference Papers, 400 pages	£5 6 0
*Volume 32	Controlled Fusion Devices, 59 Conference Papers, 462 pages	£5 6 0
Volume 33	Index of the Proceedings (Author, Numerical, Subject)	£5 18 0

***AVAILABLE NOW**

Other Groups:

NUCLEAR MATERIALS, 4 volumes, 325 Conference Papers, including Survey & Processing of Raw Materials, etc.

PHYSICS, 4 volumes, 287 Conference Papers, including Nuclear Physics & Instrumentation, Fundamental Physics, etc.

CHEMISTRY, 6 volumes, 357 Conference Papers, including Processing Irradiated Fuels and Radioactive Materials; Isotopes in Research; etc.

BIOLOGY AND MEDICINE, 7 volumes, 516 Conference Papers, including Biological Effects of Radiation; Isotopes in Biochemistry & Physiology; etc.

FOR FURTHER INFORMATION CONSULT YOUR LOCAL BOOKSELLER OR:

UNITED NATIONS

Sales and Circulation, Geneva, Switzerland

Descriptive brochures available on request

BOSTON MARINE & GENERAL ENGINEERING CO. LTD.

Dept. NE., HEATH TOWN WORKS, DEANS ROAD, WOLVERHAMPTON
Tel: Wolverhampton 23901

APPOINTMENTS

DRAUGHTSMAN (H & V), knowledge of electrical work an advantage. Consulting Engineers. Five day week, L.V. State age, wage and experience. Box No. 1026, NUCLEAR ENERGY ENGINEER, 147, Victoria Street, Westminster, S.W.1.

HEATING INTERMEDIATE DRAUGHTSMAN required in London, accustomed to design with minimum supervision. Salary up to £1,000 per annum to right man. Permanent position with pension facilities and excellent prospects. Write in confidence, stating full details of age, experience and past employers to Ellis (Kensington) Ltd., Kendrick Place, London, S.W.7.

TEMPERATURES AND DEGREE DAYS

A handy pocket size booklet containing daily temperatures, humidity data and degree days for the heating season 1957/58.

This comprehensive booklet is available to all Heating and Air Treatment Engineers.

Price 6d. Post free

from

"Heating and Air Treatment Engineer"
Book Department,
147 Victoria Street, London, S.W.1.

Printed and Published by Princes Press, Ltd., 147, Victoria Street, Westminster, S.W.1. Conditions of Sale and Supply.—This periodical is sold subject to the following conditions, namely, that it shall not, without the written permission of the publishers first given, be lent, resold, hired out or otherwise disposed of by way of trade except at the full retail price of three shillings and sixpence, and that it shall not be lent, resold, hired out or otherwise disposed of in a mutilated condition or in any unauthorised cover by way of trade; or affixed to or as part of any publication or advertising, literary or pictorial matter whatsoever.

Ask for Specimen Copy

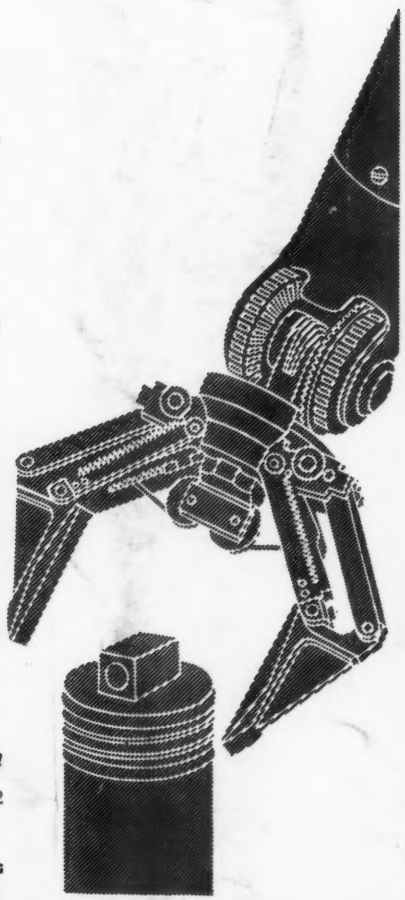
Princes Press Publications

147 Victoria Street, London, S.W.1.

SO LONG AS THERE'S CORROSION . . .

THERE'LL ALWAYS BE APEXIOR REGISTERED

In all the changes of over fifty years, APEXIOR has been a sure shield against the costly ravages of corrosion. So it will remain. Whether the source of power be coal, oil or nuclear reaction, "APEXIOR NUMBER 1" will still ensure the most reliable protection for the internal surfaces of all steam-raising plant—wherever wet-heat temperatures between 170°—1000°F are encountered. "APEXIOR NUMBER 3" is equally trustworthy in cold-wet conditions up to 125°F and for the prevention of corrosion by galvanic action on the stern parts of ships. Send for your copy of the Apexior Manual today.



DAMPNEY'S APEXIOR REGISTERED

"Apexior" is being used at Stations throughout the U.K. Atomic Energy Authority.

SUREST SAFEGUARD AGAINST CORROSION

BRITISH PAINTS LIMITED *'Apexior' Division*

PORTLAND ROAD, NEWCASTLE UPON TYNE, 2

LONDON AND LIVERPOOL

OUR WORLD-WIDE SERVICE IS AT YOUR DISPOSAL FOR THE ASKING

SYDNEY · ADELAIDE · TORONTO · DURBAN · CAPE TOWN · CALCUTTA · TRINIDAD · NEW YORK · DUBLIN